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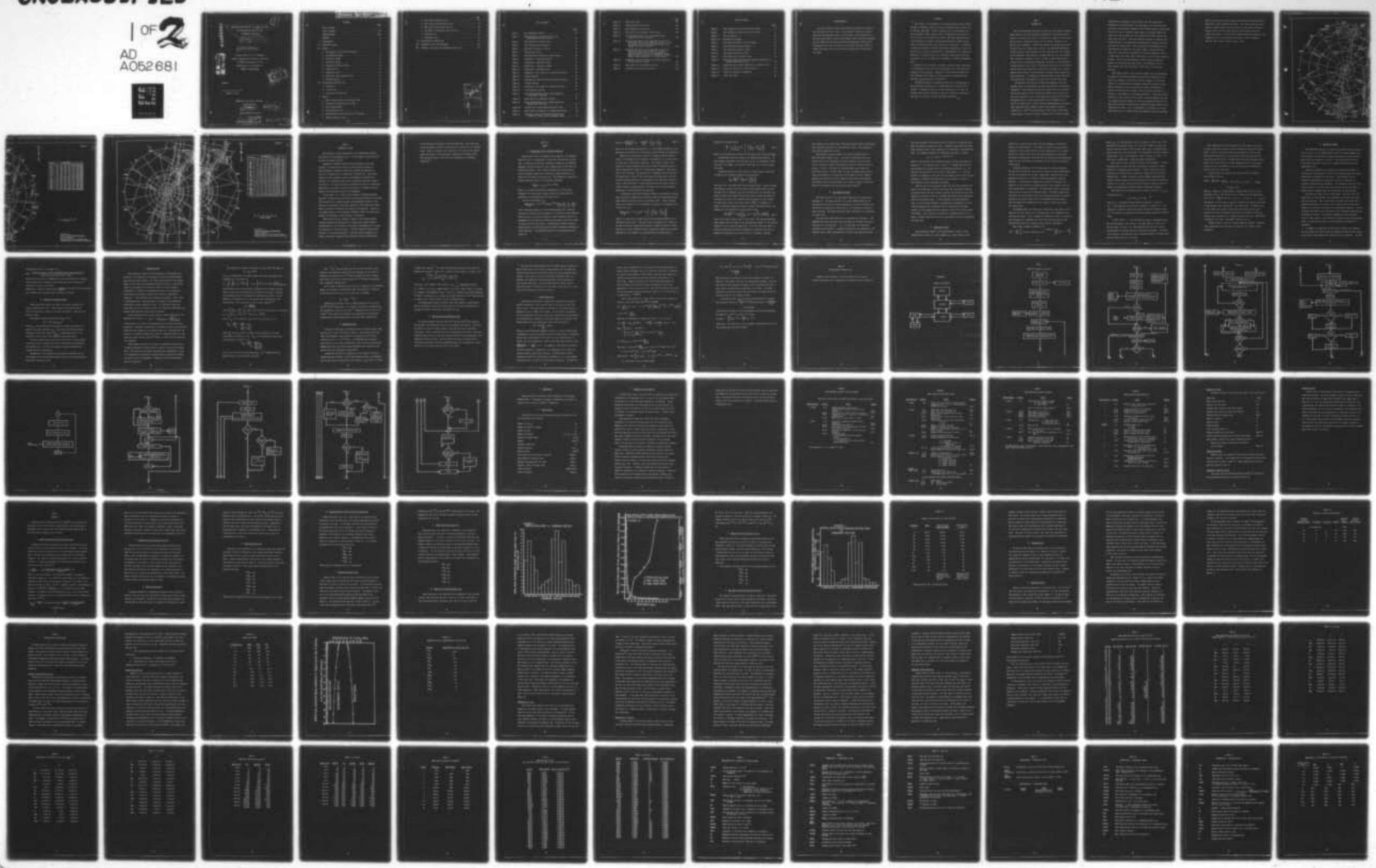

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(6) RADIATION DOSE ANALYSIS OF A PWR 1 ACCIDENT

FOR THE PROJECTED REACTOR SITE

AT CEMENTON, NEW YORK.

(9) Master's thesis.

by

(10) John D. Huncharek

A Thesis Submitted to the Graduate

Faculty of Rensselaer Polytechnic Institute

in Partial Fulfillment of the

Requirements for the Degree of

MASTER OF ENGINEERING

Approved

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Rensselaer Polytechnic Institute

Troy, New York

(11) March 1976

(12) 159p.

(For graduation May 1976)

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ACKNOWLEDGEMENT

The author wishes to thank many people who provided aid, support, and information for this study: To Mr. Robert M. Ryan for technical review and encouragement, Mssrs. Sam Syrotynski and Tom Reamon of the New York State Bureau of Public Water Supply, Mssrs. William Trollenberg and Don Rexford of the Office of Disaster Preparedness, Radiological-Intelligence Section of the Division of Military and Naval Affairs in Albany, New York, and to the Troy District Engineers for information and ideas.

ABSTRACT

This study is an evaluation of a pressurized-water reactor (PWR) 1 accident as defined by WASH 1400 for the proposed nuclear reactor site at Cementon, New York. Using an extension of the Environmental Protection Agency's AIREM computer code, the following were analyzed for up to 50 miles for 16 compass directions: (a) whole body doses due to cloud submersion, inhalation and ground deposition; and (b) thyroid, lung, and gastrointestinal tract doses due to inhalation. In addition, a model was developed to simulate population evacuation up to both 10 and 50 miles and again determine doses. Subsequently, the nuclide concentration in drinking water, milk, and fish in the area of interest is examined, as well as doses due to swimming in a nearby contaminated lake.

Iodine 131 is the isotope of concern, being the major contributor to the inhalation dose which itself contributes 60% of the total dose received in this instance. Comparison of this study with WASH-1400 shows agreement with respect to total man-rem and individual doses received, and resulting acute lethalities.

Finally, evacuation, a significant mode of dose reduction is examined, ~~and~~ an alternate plan of seeking shelter in the event of an accident is suggested because at close proximities to the site, the average winds would be expected to carry the radioactive cloud downwind much too quickly to permit successful evacuation.

PART I

INTRODUCTION

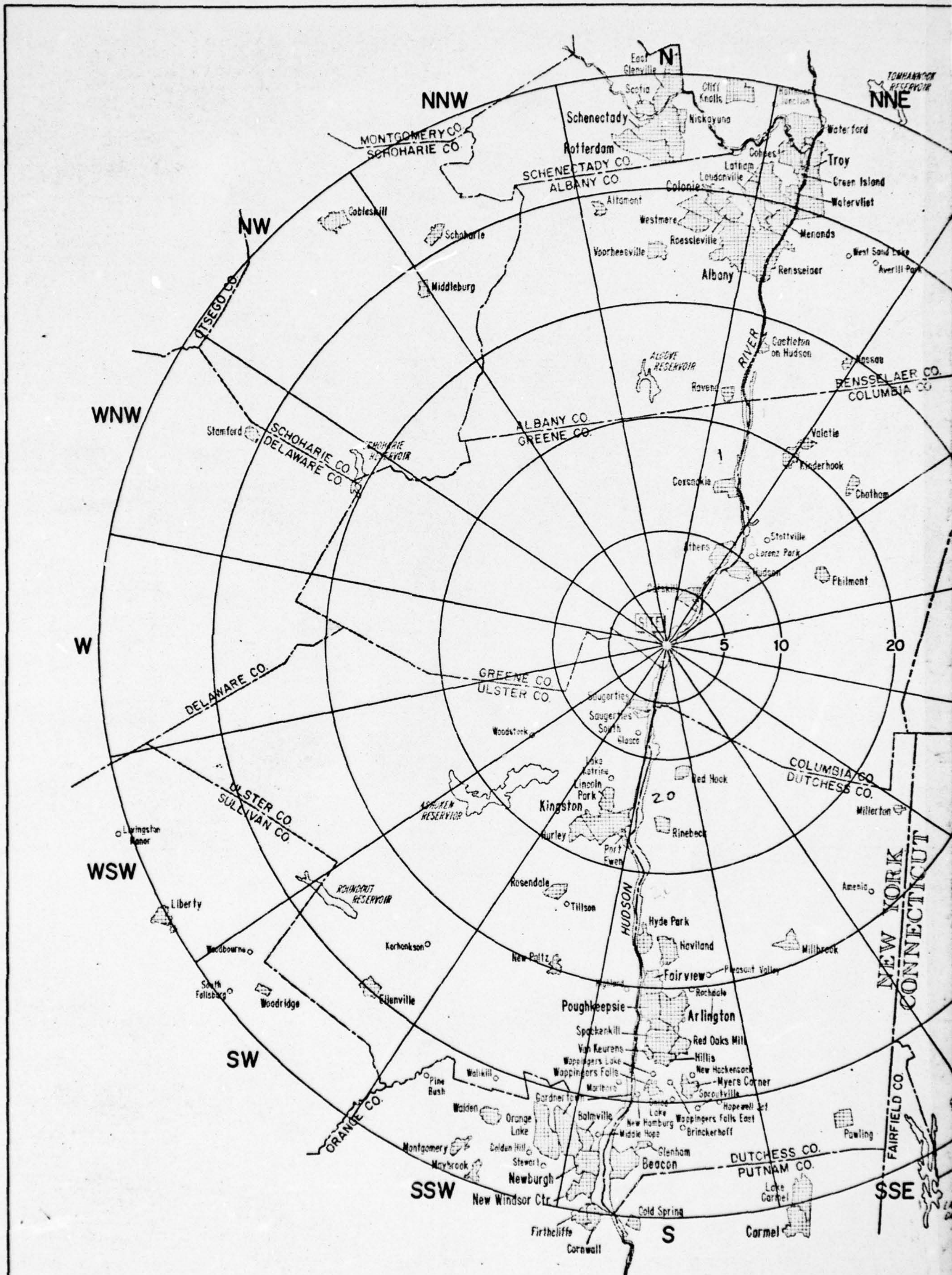
With the controversy and public concern over the safety of nuclear power reactors, and the proposed construction of a pressurized water reactor at Cementon, New York, it is relevant to examine a severe accident in which a significant portion of the isotope inventory is released to the atmosphere. Rather than examine the design base accident in which there is a large loss of coolant, the engineered safeguards function properly, and therefore, the core does not melt, but leakage to the atmosphere takes place at a design leak rate, the less probable PWR 1 accident is assumed to occur. In Ref. 2, this event assumes a failure of all the engineered safeguards resulting in a core meltdown, a steam explosion upon contact of molten fuel and water in the pressure vessel causing the vessel head to penetrate containment with a subsequently large portion of the radioactive inventory being released outside containment. No mechanism is postulated here for how this would take place since the assumption is made that the event does occur.

In WASH-1400, with the use of fault-tree analysis, the worst possible events are postulated and their probabilities of occurrence determined. Since neither an event this serious has ever occurred in the nuclear industry, these statistical studies must be used as the next best alternative; nor is there taken into account the fact that the probability of a PWR 1 type accident for the average case is 7×10^{-7} per reactor-year, and for the worst meteorological, and population conditions which combined results in the highest number of lethalities is 7×10^{-10} or one accident of this type in one billion reactor years or with 100 reactors running, one in 10 million years.

Although this probability is much smaller than other man-made or naturally-occurring disasters, the psychology of the American public and indeed of any general populace, but the United States in particular, first of all has no concept of very large or very small numbers and second, has come to equate the word "nuclear" with great destructive power ever since 1945. Since the industry has grown in secrecy, only a small fraction of the population understands the concepts, benefits and risks of nuclear power. With the emotional vulnerability of the vast majority of people who only wish a light to appear when they turn it on. they are more susceptible to emotional arguments than to a logic which they either cannot understand, or has not been presented clearly. Most of the more important decisions made by people in general are ultimately made emotionally, not logically, and it is this concept which must be evident to both sides of the nuclear question.

This study, however, will only deal further with the psychology of people in the portion dealing with population evacuation in the case of an accident. The central idea is to assess the short-term results to the surrounding countryside, population, bodies of water, and milk production, and to determine the doses to individuals at various locations from the reactor sites from three mechanisms: inhalation, cloud submersion, and ground deposition. Since acute fatalities are of most concern in this study, a 30-day integrated dose due to a single short-term exposure is used for inhalation doses for the whole body and lung, and essentially infinite (50 years) doses to the thyroid and GI tract. Also, the population is assumed to be a year 1990 projection in a 50-mile radius from Cementon, and the prevailing

winds used are those on-site readings taken while writing the Cementon Construction Stage Environmental Report. The release rate and meteorology is assumed constant over both space and the period of release (several hours) and the study concerns itself primarily with dry weather conditions. It also did not assume increased scrubbing out of contamination due to land profile (mountains, trees, buildings). The area under study is shown in Figs. 1 and 2.


N
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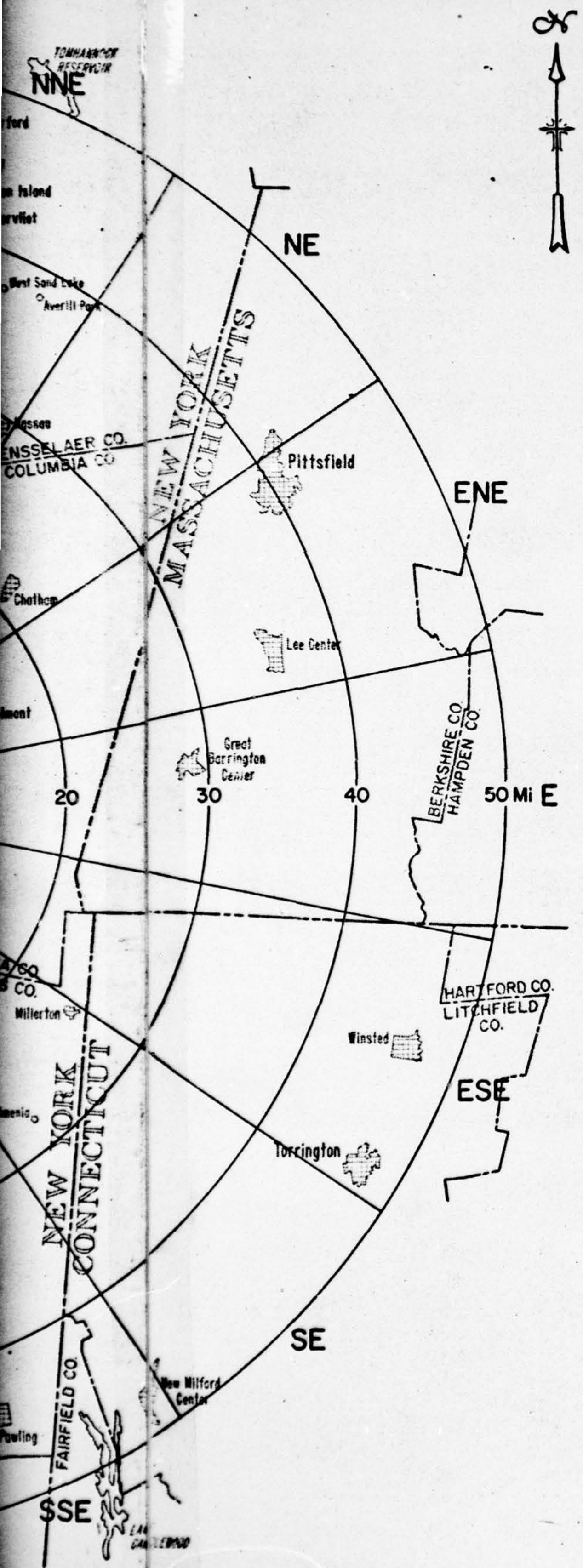
NNW
NW
WNW
W
WSW
SW
SSW
S
SSE
5
10
20
SITE
MONTGOMERY CO.
SCHOHARIE CO.
SCHENECTADY CO.
ALBANY CO.
OTSEGO CO.
SCHOHARIE CO.
DELAWARE CO.
ALBANY CO.
GREENE CO.
RENSSELAER CO.
COLUMBIA CO.
GREENE CO.
ULSTER CO.
DELAWARE CO.
ULSTER CO.
SULLIVAN CO.
COLUMBIA CO.
DUTCHESS CO.
ORANGE CO.
DUTCHESS CO.
PUTNAM CO.
FAIRFIELD CO.
NEW YORK
CONNECTICUT
RIVER
HUDSON
East Glenville
Scotia
Cliff Knolls
Schenectady
Niskayuna
Waterford
Rotterdam
Cohoes
Troy
Latham
Loudonville
Colonie
Green Island
Watervliet
Altamont
Westmere
Menands
Cobleskill
Schoharie
Roessleville
Voorheesville
Albany
Rensselaer
West Sand Lake
Averill Park
Middleburg
Castleton on Hudson
Nassau
Ravena
Stamford
Valatie
Kinderhook
Coxsackie
Chatham
Stottville
Athens
Lorenz Park
Hudson
Philmont
Saugerties
Saugerties South
Glasco
Woodstock
Lake Katrine
Lincoln Park
Red Hook
Kingston
Hurley
Port Ewen
Rhinebeck
Millerton
Livingston Manor
WSW
Liberty
Rosendale
Tillson
Amenia
Hyde Park
Haviland
Kerhonkson
Millbrook
Woodbourne
New Paltz
Fairview
Pleasant Valley
South Fallsburg
Woodridge
Ellenville
Rochdale
Poughkeepsie
Arlington
Spackenkill
Red Oaks Mill
Van Keurens
Hillis
Wappingers Lake
Wappingers Falls
New Hackensack
Myers Corner
Walkill
Pine Bush
Marlboro
Gardnertown
Sproutville
Walden
Orange Lake
Balmville
New Hamburg
Wappingers Falls East
Brinckerhoff
Middle Hope
Pawling
Montgomery
Maybrook
Stewart
Glenham
Beacon
Newburgh
New Windsor Ctr
Lake Carmel
Cold Spring
Firthcliffe
Cornwall
Carmel

Figure 1



DIRECTION	DISTANCE (MILES)						TOTAL
	0-5	5-10	10-20	20-30	30-40	40-50	
N	257	1,337	3,877	12,015	114,379	206,028	537,893
NNE	1,135	5,109	7,869	22,805	133,932	172,068	342,918
NE	318	10,915	10,639	12,012	11,436	11,437	56,757
ENE	596	1,320	6,395	3,942	47,218	35,945	95,416
E	480	923	2,769	9,952	5,085	3,913	23,122
ESE	570	765	1,936	5,517	9,232	57,632	75,652
SE	653	872	3,720	16,135	10,032	25,033	56,445
SSE	806	2,580	6,499	14,100	28,398	48,023	100,406
S	222	4,446	19,868	60,004	182,797	173,686	441,023
SSW	1,441	15,094	58,206	27,903	18,037	76,131	196,812
SW	1,046	2,758	8,790	7,530	17,213	18,778	56,115
WSW	1,010	2,213	6,998	3,130	1,737	11,517	26,605
W	542	1,168	989	2,234	4,008	2,542	11,483
WNW	348	595	1,794	1,840	3,371	5,794	13,742
NW	413	1,257	2,550	2,334	2,528	12,596	21,678
NNW	260	1,266	3,796	3,430	6,491	12,356	27,599
TOTAL	10,097	52,618	146,696	204,883	595,894	873,479	1,883,666

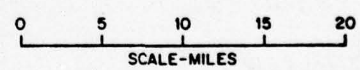
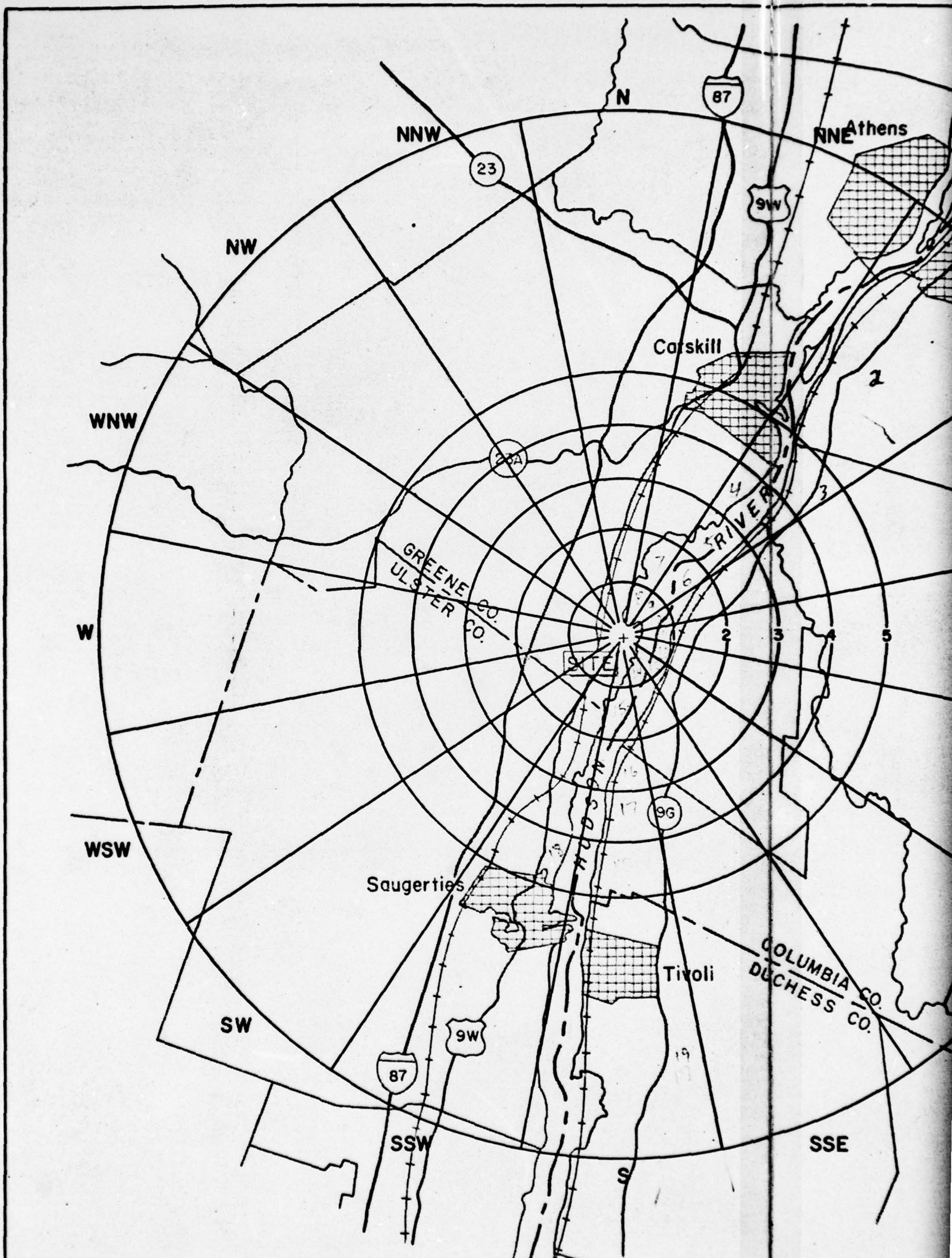
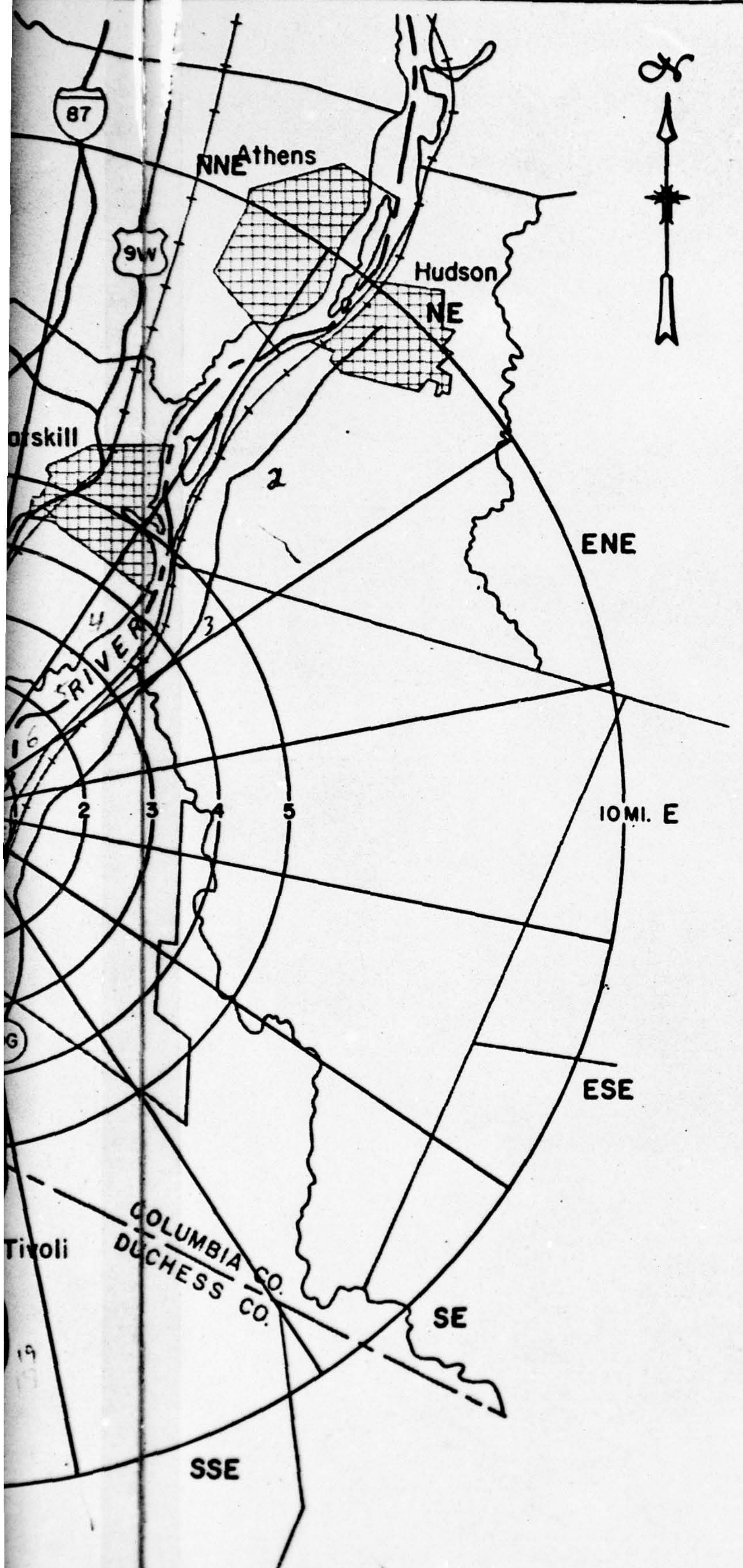


FIGURE 2.2-16
1990 POPULATION DISTRIBUTION
50 MILE RADIUS
GREENE COUNTY NUCLEAR POWER PLANT
POWER AUTHORITY OF THE STATE OF NEW YORK



N
NNE
NNW
NW
WNW
W
WSW
SW
SSW
S
SSE
87
23
9W
23A
9G
Athens
Catskill
Saugerties
Tivoli
GREENE CO.
ULSTER CO.
COLUMBIA CO.
DUCHESS CO.
HUDSON
RIVER
SITE
2
3
4
5

Figure 2



DIRECTION	DISTANCE (MILES)						TOTAL
	0 - 1	1 - 2	2 - 3	3 - 4	4 - 5	5 - 10	
N	3	3	23	48	180	1,337	1,594
NNE	0	0	44	52	1,039	5,109	6,244
NE	0	17	55	139	107	10,915	11,233
ENE	0	193	143	130	130	1,320	1,916
E	3	127	73	110	167	923	1,403
ESE	3	213	155	123	76	765	1,335
SE	0	308	143	92	110	872	1,525
SSE	0	245	167	178	216	2,580	3,386
S	0	13	32	73	104	4,446	4,668
SSW	3	175	215	543	505	15,094	16,535
SW	100	272	122	348	204	2,758	3,804
WSW	41	0	237	153	579	2,213	3,223
W	11	11	111	66	343	1,168	1,710
WNW	3	29	15	90	211	595	943
NW	0	0	92	59	262	1,257	1,670
NNW	3	8	82	82	85	1,266	1,526
TOTAL	170	1,614	1,709	2,286	4,318	52,618	62,715

0 1 2 3 4 5

SCALE - MILES

FIGURE 2.2-8
1990 POPULATION DISTRIBUTION
10 MILE RADIUS
GREENE COUNTY NUCLEAR POWER PLANT
POWER AUTHORITY OF THE STATE OF NEW YORK

PART II

HISTORICAL REVIEW

The basis for the dose calculation is the application of diffusion theory to the atmospheric case. In this regard, the state of the art will be briefly sketched.

Atmospheric diffusion theories first developed by Fick were attempts to use macroscopic models of the molecular processes of heat and momentum transfer in which the transfer was described in terms of its gradient and a coefficient of diffusivity. These early models then were attempts to solve the differential equations and determine the coefficients which would accurately represent the physical process. The major difficulty encountered was that the coefficients were found to vary with the size of the process, the height above the ground, and the physical state of the atmosphere.

By the 1920's, G. I. Taylor had introduced a statistical-motion approach to diffusion which was based on continuous movement of particles. This theory did not consider dynamic and thermodynamic causes of turbulence, but it began to techniques employed in many models used today. Sutton's equation of diffusion are based on this approach. Because of the complex nature of the atmosphere, diffusion theory has always been linked with knowledge of the processes of turbulence.

Both Sutton and, more recently, Pasquill, have devised methods involving Gaussian interpolation in a formula that relates downwind concentrations to the vertical and horizontal concentrations in a plume as a function of time and distance. Sutton's equations relate concentrations to the vertical gradient of the wind speed, atmospheric turbulence and surface roughness while Pasquill's relate concentrations

to wind direction fluctuations and wind speed only. This study uses a form of Sutton's equation, the derivation of which will be developed later. There is currently work being done in the area of the earlier neglected dynamic and thermodynamic mechanisms of turbulence which will hopefully prove to yield the next improvements in diffusion techniques.[10]

PART III

THEORY

A. Development of the Diffusion Equation

Because this study is dependent on and limited by the diffusion equation used, it is appropriate to show how this equation has been used. As mentioned previously, diffusion according to the gradient transport theory developed by Fick is proportional to the local concentration gradient. Fick's theory considers fluid motion from a fixed co-ordinate system while statistical theories generally consider motion following fluid particles. The fundamental equation of Fickian diffusion theory is for isotropic diffusion,

$$\frac{\bar{q}(r,t)}{Q} = (4\pi Kt)^{-3/2}\, e^{-r^2/4Kt}$$

where K is a constant diffusivity coefficient, Q is the source strength, the total amount released, and $\bar{q}$ is the mean value of a conservative air property per unit mass of air.

For the non-isotropic case

$$\frac{\bar{q}(x,y,z,t)}{Q} = (4\pi t)^{-3/2}(K_x K_y K_z)^{-1/2} \exp\left[\frac{-1}{4t}\left(\frac{X^2}{K_x} + \frac{Y^2}{K_y} + \frac{Z^2}{K_z}\right)\right]$$

Fick's diffusion equation is solved statistically with a Gaussian distribution which has been described as a continuous source diffusion model by Sutton, and does not apply for short diffusion times or inhomogeneous or non-stationary conditions although it will show trends if these conditions are altered. Average plume diffusion formulas usually assume an instantaneous point source of material diffusing in three dimensions. The Gaussian formula for an instantaneous point source is:

$$X(x,y,z) = \frac{Q(2\pi)^{-3/2}}{\sigma_x \sigma_y \sigma_z} \exp \quad -\frac{(x-\bar{\mu} t)^2}{2\sigma_x^2} + \frac{y^2}{2\sigma_y^2} + \frac{z^2}{2\sigma_z^2} \qquad \text{Eqn. A}$$

where X is the average concentration, σ is the standard deviation of the distribution of material in a plume and $\bar{\mu}$ is the average wind component.

There are two restriction, however, in using the above equation. First, it is assumed that the equation is separable in x, y and z, that is, there are no cross-wind components. The second is based on the concept of relative diffusion which states that the equation cannot be used to describe the spread of a single puff of material. This can be seen by the following. The maximum rate of diffusion from a fixed axis is proportional to time t^2 since the cloud can diffuse only in two directions (downwind diffusion is negligible due to the equal concentrations in that direction). Average diffusion from the center of mass of a puff, however, is proportional to t^3 since there are three possible directions in which diffusion can take place.

A continuous point-source diffusion formula is obtained by assuming that the plume is composed of an infinite number of overlapping average puffs carried along the x-axis by an average wind $\bar{u}$. Again, assuming there is no diffusion in the x direction, equation A is integrated over t from 0 to ∞ as,

$$\frac{\bar{X}(x,\ y,\ z)}{Q'} = (2\pi\sigma_y\sigma_z\bar{u})^{-1} \exp\left[-\left(\frac{y^2}{2\sigma_y^2} + \frac{z^2}{2\sigma_z^2}\right)\right]$$

where Q' is the source strength-time rate of material emission from a continuous point source. The point source is assumed to be located at or near the earth's surface which presents a physical barrier to diffuwion and as in heat conduction theory, assuming an image source located symmetrically with respect to the ground plane, and assuming the

receptor is at ground level,

$$\frac{\bar{X}}{Q'} = \frac{1}{\pi \sigma_y \sigma_z \bar{u}} \exp \left[- \left(\frac{y^2}{2\sigma_y^2} + \frac{h^2}{2\sigma_z^2} \right) \right] \qquad \text{Eqn. B}$$

where h is the effective elevation of the source above the ground plane.

Statistically the above equation is completely determined by σ^2 and it agrees reasonably well with much, but not all atmospheric diffusion data; for example, the equation breaks down in the case of severe wind shear.

Integrating Equation B with respect to y from $-\infty$ to ∞ yields what is known as the crosswind integrated concentration,[9]

$$\bar{X}_{CWI} = \left(\frac{2}{\pi} \right)^{\frac{1}{2}} \frac{Q'}{\sigma_z \bar{u}} \exp \left[\frac{-h^2}{2\sigma_z^2} \right]$$

Over some time t, the mean wind $\bar{u}$ will generally shift. With an average concentration estimate over time which is much greater than over which the mean wind is computed, X_{CWI} can be multiplied by the frequency with which the wind blows toward a particular location during the period.[11] Dividing this result by the distance from the source at each location for each sector (where each sector width is $\frac{2\pi r}{n}$; r = distance, n = number of sectors), adding the effect of simple radiological decay, and summing the wind frequencies at each sector yields,

$$\frac{X}{Q'} = \left(\frac{2}{\pi} \right)^{\frac{1}{2}} f \exp \left(\frac{-h^2}{2\sigma_z^2} \right) \exp(-\lambda t) \Big/ \left(\bar{u}\, \sigma_z \left(\frac{2\pi r}{n} \right) \right) \qquad \text{Eqn. C}$$

which is the basic equation used in this study. The Gaussian depletion model assumes that the shape of the concentration profile in the vertical direction is not altered by deposition. If on the other hand there is vertical mixing and the cloud is depleted at the bottom, the point of maximum concentration moves up the cloud as t increases, carrying

more material over a larger area, reducing the ground level concentrations with subsequent reductions in doses and dose levels. This assumption then yields conservative results.

The diffusion equation spreads the activity uniformly across a given 22½ degree compass sector. As long as the release occurs over several hours, this averaging may be quite realistic since the wind, even if relatively steady, would probably show minor shifts during the period. If this is the case, the Gaussian single plume model will yield high results. In this study, the time is assumed long enough to allow the assumption of a long plume to be formed but short enough to minimize wind shifts out of the respective wind sector being studied. The computer code is not applicable nor is there a study of strong wind shifts or wind shears that the plume may pass through.[10]

B. The MODAIREM Program

The major portion of the main AIREM Program used is described in Reference 10. The major additions to the main AIREM Program are the calculations of doses due to ground deposition of various nuclides, and the effect of evacuation on total doses to the individuals and populations concerned. The ground deposition dose calculations are considered in Section IIIi.

The evacuation model employed is as described in Reference 2. The MODAIREM Code reads population data and computes individual and population doses for the unevacuated case. In this code, two additional alternatives are possible: evacuation outside the outer boundary of the outermost radius under consideration (50 miles), and evacuation beyond

the outer boundary of the middle radius (10 miles) in a direction away from the impending radioactive cloud. Therefore, those who have successfully evacuated before cloud passage do not contribute to the population dose. The original population is modified by the factor F_i where,

$$F_i = A + (1-A)\, e^{-\lambda(t_i - TL + T)}$$

where A = the fraction of the population that for some reason does not evacuate, λ = the evacuation rate in days^{-1} = $.693/T_{1/2}$ where $T_{1/2}$ is the time necessary to evacuate half of the remaining population, t_i = the time for the radioactive cloud to move to mesh point i, T = the time between the awareness of the core melt and leakage, and TL= the time lag necessary to interpret the data and issue the warning to evacuate. T and TL may be fully or partially concurrent.

With the use of the evacuation model, the code then recomputes the dose to the individual, and the total doses from the pathways desired. For ground deposition doses during evacuation, the passage of the cloud begins the delivery of dose to a receptor and continues until departure from the contaminated area. In the inhalation and cloud submersion case, the man-rem dose depends on the population remaining at the time of cloud passage while the ground dose is a function of the people present at cloud passage and those present at the end of a given period of interest. Since the man-rem dosage due to ground deposition is so small, a linear relationship which is conservative is used to approximate the total dose.

C. Subroutine RIVCON

This subroutine computes the concentrations in PCi/l of the radionuclides listed in the main program for a river flowing in the

vicinity of a nuclear power plant which has undergone an accidental release of fission products. The river is divided into reaches which correspond to mesh points (MM II), and the concentration of a certain nuclide in a reach is the sum of the direct deposition on the reach, the decayed concentration of nuclide that has travelled from the previous reach, and the concentration discharged into the river by the released cooling water.

Two major assumptions in this subroutine are that the deposited nuclides mix well with the river water to yield a uniform concentration, and that the particle size is small enough that transportation of the deposited nuclide not in solution is well approximated by solution transport. Considering the lengths of the reaches involved and the dispersal of the nuclides over large amounts of river surface area, the first approximation is reasonable. The second will result in conservatively high calculations for untreated water. The effect becomes more noticeable for treated water since water treated by municipal treatment facilities has all or nearly all of its suspended nuclides removed. For this reason, the solubility of the nuclide is taken into account for treated water.

The program takes into account the varying times and velocities of high and low tide, allows up to 19 reaches and up to 20 profiles (cross sections) per reach. Up to 11 depths per profile are used in a Simpson's Rule integration to determine the river cross sectional area at each location from which flow volumes in each reach are determined.

The solution transport equation is,[31]

$$C_{x,t} = \frac{1}{Q_{x,t}} \left[Q_{x-\Delta x,t-\Delta t} C_{x-\Delta x,t-\Delta t}\, e^{-\lambda(t+\Delta t)} + \sum_{i=1}^{m} Q_i C_i\, e^{-\lambda t} \right]$$

where $C_{x,t}$ = the concentration (pCi/l) at reach x at time t, Δx = the distance of the previous reach, Δt = the time it takes to travel the previous reach and arrive in the current reach, Q_iC_i = the direct deposition (pCi/sec) on the river and/or the discharge of the plant through cooling water, $Q_{x,t}$ = the streamflow (l/sec) in reach x at time t, t = time (days) concentration is measured after contamination.

Four types of water treatment facilities are considered. A Class 1 treatment plant utilizes only water chlorination and does not reduce dissolved or suspended nuclide amounts. A Class 2 facility utilizes filtration and chlorination to remove all suspended but no dissolved radionuclides. A Class 3 facility involves chemical processing that removes variable amounts of dissolved nuclides and nearly all suspended nuclides and a Class 4 plant filters and chemically processes water to remove all suspended and variable amounts of dissolved nuclides.

The treated water concentration for nuclide l in reach i, C_{il} can be represented as:

$$C_{il} = F'W'_{il} + F'' W''_{il} \qquad 31$$

Where W'_{il} + the dissolved concentration of nuclide l in reach i, W''_i = the suspended concentration of nuclide l in reach i, F' = the fraction of dissolved nuclide that passes through the treatment plant, F" = the fraction of suspended nuclide that passes through the treatment plant.

In this study, F' = 1 for nuclides for which no experimental data has been developed to the contrary. For plant types 2, 3 and 4, F"= 0 and for types 1 and 2, F' = 1. The subroutine also sums the nuclide concentrations by reaches before and after water treatment. If RIVCON is not desired, one blank card can be inserted instead of the data cards and the subroutine will not be used.

When computing water concentrations in river reaches, the time it takes a particle of water to travel through the reach must be determined. To do so, the particle must be moved with the tide up- and down-stream according to the up- and down-stream velocities and the time of ebb and flow tides. RIVCON follows the particle from the first reach at the outer limits of interest beginning with the tide going either in or out as specified to the last reach while retaining the times of travel in each reach.

In each reach, the vertical cross sectional area is computed using Simpson's Rule or,

$$\text{CROSS} = \int_a^b f(x)dx = \frac{\Delta X}{3}(yo + 4y_1 + 2y_2 + 4y_3 + 2y_4 + \ldots + 2y_{2m-2} + 4y_{2m-1} + y_{2m})$$

where $y_k = f(x_k)$, y_k corresponding to profile depths and x_k to each equidistant width. The interval a to b is broken into 2m equal parts of width $\Delta x = \frac{b-a}{2m}$ so that $x_o = a$, $x_1 = a +\ \ x$, $x_2 + 2\ \ x \ldots x_{2m} = b$. The constant a is set equal to zero at one and of the shore of the river at each profile and b corresponds to the river width. In RIVCON, from 3 to 11 depths can be used to chart the river bottom with up to 20 profiles per reach to provide as much detail as possible to find the average cross sectional area. Several constants used are: .0929 m^2/ft^2, 9.99972×10^2 ℓ/m^3, and 4.470193×10^{-1} m/sec per mi/ hr.

RIVCON overlays a river on a ground deposition pattern. Sedimentation, resuspension and the effects of dams are not included in this subprogram.

D. Subroutine LAKEDS

This subroutine computes the treated and untreated water concentrations in pCi/ l of the radionuclides listed in the main program for a lake located within the area of interest surrounding a nuclear power plant which has undergone an accident. The concentrations are used to determine individual doses due to swimming and/or boating on the contaminated lake.

The lake is assumed to fit primarily in one mesh point (MM, II) with mixing of the deposited nuclides in the water to obtain an average concentration throughout the lake water. Small particle size is assumed in using solution transport as the water is removed to a treatment facility before consumption. The subroutine allows for decay of the nuclides in the lake, but once the water has been treated, no further decay is assumed since the water may be used at any time.

The user has several options using LAKEDS. With the use of one blank card, the calculations will be deleted and no other data cards are then necessary. When using LAKEDS, the doses can be found due to swimming and boating for whatever time is spent in or near the water. Either of the two dose calculations can be deleted if desired. For each activity, skin and/or whole body doses can be calculated and either may be deleted if desired. In the water treatment section, entering a class 1-4 will result in concentrations of treated water being displayed while a 0 entered will assume no water treatment and terminate the subroutine.

In LAKEDS, the whole body and skin dose of factors for swimming for each isotope are entered, and the boating dose factors are computed as one half of the emersion dose factors due to the geometry. The lake

concentration (pCi/l) of isotope i is,

$$CON_i = \frac{(\text{Activity density pCi/m}^2)(.0929\text{m}^2/\text{ft}^2)(\text{lake surface area ft}^2)}{\text{Lake volume (gallon)}(3.78541\ \ell/\text{gal})}$$

The whole body dose due to swimming, the whole body dose due to boating, the skin dose due to swimming, and the skin dose due to boating are found with equations of the type:

$$\text{DOSE (mrem)} = \text{CON(pCi/l)(Dose factor } \frac{(\text{mrem/hr})}{(\text{pCi/l }\ )}\text{ (time spent (hr) in activity)}$$

As in RIVCON, water treatment facility usage is included.

E. Subroutines FISHR and FISHL

These subroutines compute the amount of various nuclides due to their concentration in fish. FISHR computes the concentrations in fish in each reach of a river in the area of interest. FISHL does the same in a lake.

The equation used for each reach and the lake is,

$$C_{LL} = CF_{LL}\ (A)^{31}_{MM,II,LL}$$

where C_{LL} = the concentration of nuclide LL in fish in the lake or a reach in the river (pCi/kg); CF_{LL} = fresh water concentration factor (pCi/kg per PCi/l)(see Table); $A^{LL}_{MM,II}$ = concentration (pCi/l) of nuclide LL in the river or lake located in mesh point MM,II.

The above concentrations assume that the fish do not move significantly away from the original mesh point location where they obtained the concentration. The fish are assumed to rapidly assimilate the nuclides from the surroundings.

Sedimentation and resuspension are implicitly considered in the fish ingestion dose calculations through the use of the reconcentration factors for fresh water fish.

F. Subroutine MILK

This subroutine computes the concentration of radionuclides in milk due to the ingestion of nuclides by the dairy cow which depends upon its mesh point location. The first calculations are for a given number of days after the accident specified in the data. MILK allows either the evacuation of the dairy cow after one day of exposure (equivalent to a change to uncontaminated feed) or its remaining in place during the period of interest and eating the contaminated vegetation. Three drinking water options are available: river, lake, or underground well. Each mesh point is assumed to use underground wells unless entered otherwise as data. If a mesh point area uses river water and is not located on the river, subroutine REACH finds the closest reach and uses water from that location.

If the evacuation mode is used, decay is allowed according to the effective half-life, i.e., $\lambda_{eff} = \lambda_{radiological} + \frac{.693}{T\frac{1}{2}biological}$.

If evacuation is not used, the concentration for the initial period is determined. Subsequent concentrations are added to earlier concentrations which have been decayed by the effective half life. Concentrations are printed for specified increments of days for a specified length of time unless all doses are less than 10^{-10} pCi/l at which time the subroutine will terminate.

MILK assumes that there is no decay in transmission because there is rapid transmission of water from its origin to its place of consumption. This subroutine considers only forage crop contamination since it is assumed that stored feed and grain would be covered and probably not sold or used if contaminated. Therefore, the use of 100% forage crop is conservative.

The equation for nuclide concentration in milk is,[31] (see Table 11)

$$C_d = S_d I_d \ \text{pCi/l}$$

but I_d is modified due to accident rather than long term analysis and redefinition of some terms as

$$I_d = \left\{ Q_f \left[\frac{R}{Y_f} (D_f) + \frac{B_f}{P} (F_f) \right] + L_d W \right\} \times \left(\text{Decay Factor} \right) \quad \begin{array}{l}\text{pCi/day}\\ \text{total ingestion.}\end{array}$$

Terms similar to the ones enclosed in brackets for the forage crop are found for grain and stored feed but are neglected as stated. Likewise, any concentration due to inhalation of radionuclide particles is very difficult to determine but is much smaller than concentrations from other sources. The second term is due to water ingestion.[31]

$$S_d = \frac{\text{pCi/l}}{\text{pCi/day}}$$

If $A \equiv Q_f \left[\frac{R}{Y_f} D_f + \frac{B_f}{P} F_f \right]$ and $B \equiv L_d W$, then for the case of no evacuation,

$$C_d = S_d \left[A \left(1 - e^{-\lambda_{e_{ei}} t}\right) e^{-\lambda_{eg_i} t} + B e^{-\lambda_{eg_i} t} \right] \qquad A$$

where $\lambda_{e_{c_i}}$ is the effective decay in the cow for nuclide i or,

$$\lambda_{e_{c_i}} = \frac{.693}{T_{\frac{1}{2}e_{c_i}}} \equiv \frac{.693}{\dfrac{T_{\frac{1}{2}b_i} \quad T_{\frac{1}{2}r_i}}{T_{\frac{1}{2}b_i} + T_{\frac{1}{2}r_i}}}$$

where $T_{\frac{1}{2}b_i}$ and $T_{\frac{1}{2}r_i}$ are the biological and radiological half-lives respectively for nuclide i, and $\lambda_{e_{g_i}}$ is the effective nuclide decay on the ground for nuclide i, or:

$$\lambda_{e_{g_i}} = \frac{.693}{T_{\frac{1}{2}e_{g_i}}} = \frac{.693}{\dfrac{T_{\frac{1}{2}g_i} \quad T_{\frac{1}{2}r_i}}{T_{\frac{1}{2}g_i} + T_{\frac{1}{2}r_i}}}$$

and t is the time after nuclide deposition. D_f = forage deposition (pCi/m^2) and F_f = soil deposition (pCi/m^2).

The $e^{-\lambda_{e_{g_i}} t}$ term describes the rate of loss of nuclide i from vegetation and radioactive decay while the remainder of the first exponential term describes the i^{th} nuclide concentration due to forage crop intake, and the last term describes the i^{th} nuclide concentration due to ingested drinking water.

For the case of evacuation after one day of ingestion of contaminated forage or switching to uncontaminated feed, the equation is identical to the previous one for C_d up to one day, then it becomes,

$$C_d = S_d I_d e^{-\lambda_{e_{c_i}} t}$$

Comparison of Equation A with a Federal Radiation Council study of Sr^{89} and Sr^{90} shows that it is initially conservative and approaches FRC calculations closely by ten days.[22] Comparison with a study of I^{131} in milk [23] also shows this equation to be conservative, both maximum concentrations peaking approximately five days after contamination.

G. Inhalation Doses

Factors for computing the inhalation doses to the whole body, lung, thyroid, and GI tract are listed in Table 1. These factors have been taken from Reference 2 and converted to mrem/sec per Ci/m^3 using a breathing rate of 2.2×10^{-4} m^3/sec. The MODAIREM Code multiplies these factors by the cloud concentration of each nuclide yielding doses from each mesh point and these values multiplied by the population per sector yield their respective man-rem doses.

Assumptions made are as in Reference 2 with respect to nuclide distribution and retention. Whole body inhalation doses are integrated over 30 days and are conservative since using an LD_{50} of 400 R is based

on short term exposure.[2] The total dose during any period of time from the assumed rapid intake at time t=o to a period t from isotope j to organ i is,[32]

$$D_{ij} = \frac{5IE_{ij}I_i \int_o^t R_{ij}(t)\exp\left(-\lambda_{eff}t\right)\,dt}{M_i}$$

where D_{ij} = rem to organ i from isotope j; $E_{ij} = \sum_{j=i}^{k} f_j F_{ij} E_j (QF)_{ij} (MF)_{ij}$; I_i = intake in μCi; R_{ij} = organ burden in μCi; M_i = mass of organ i in grams; E_j = energy of disintegration mode j in Mev; f_j = probability per disintegration of mode j's production; F_{ij} = fraction of energy emitted by the j^{th} mode absorbed in organ i; QF = quality factor; and MF = modifying factor.

The compartmental model of internal dose with feedback is approximated with an exponential reduction of organ burden by both the radiological and biological half-life resulting in an effective decay .

H. Whole Body Cloud Submersion Dose

The cloud submersion doses of WASH 1400[2] and WASH 1258[14] were compared and the WASH 1258 values were used as being slightly more current. Both sets of values are seen to be quite similar, being derived from a semi-infinte cloud model. The 2π geometry was used to determine dose factors, with gamma radiation equal from all directions and beta with short penetrating power irradiating only from one side. The dose factors have been corrected for the fractional penetration of beta and gamma radiations to the appropriate tissue depth of 5 cm for whole body and 7×10^{-3} cm for skin.

The WASH 1400 report accepted the year 2000 study with respect to dose factors since it was the best data available, but the WASH 1258 report recalculated the dose factors using the latest available decay schemes. With respect to both air and water submersion doses, an external dose depends on the penetrating power of the emissions of the nuclide under study. Beta and gamma radiation which could not penetrate 7mg/cm^2 of tissue was not considered in the skin dose. Both sets of dose factors are listed in Table 26.

I. Ground Deposition

To determine the effect of radionuclide deposition resulting in ground contamination, dose rates in terms of activity per unit area must be found. The dose rates were calculated in the manner shown in Reference 32 for a height of one meter. At this height, β radiation is not significant, and since a short term accident has been postulated, all contamination is assumed to be on the surface of the ground. The ground deposition dose factors were found using the equation,

$$DF = .869 \sum_{i=1}^{n} A_i \, DR_i \, P_i$$

where A_i is the fractional abundance of photon i in the nuclide under consideration, DR_i is the exposure rate at one meter above an infinitely smooth plane contaminated to one pCi/m^2, and P_i is the fraction of surface dose which penetrates to whole body depth (5cm) and where .869 = $\frac{\text{rads in air}}{\text{R in air}} \times \frac{\text{1 rem}}{\text{rad}}$ for γ. An example is shown below in Section J. The above equation is modified by .5 in Reference 31 to account for ground roughness and/or heavy clothing. The dose factors listed therefore are half the values shown in Reference 2. It is the unmodified value which is shown in the following calculation. The WASH 1400

values must be modified by 1/3 to account for the shielding effect of houses, office buildings, cars, etc., and even this value is conservative since a more realistic value would be less than this since more people are in protected or partially protected environments at a given time. Using 1/3 accounts for the fact that many people will leave buildings and enter cars during an evacuation, and is more appropriate in this case than ¼ or ½. Skin dose calculations were done in the same manner as whole body using a depth of 7×10^{-3} cm since P_i is affected by $e^{-\mu(\text{depth})}$.

With a decay energy of .66 MeV, 93% of the time, and assuming an infinite, thin area source, for Cs^{137} as an example,

$$S_A = \frac{\gamma}{cm^2 sec} \text{ for 1 pCi: } = 1 \times 10^{-12} \frac{Ci}{m^2} \left(\frac{1m}{100\ cm}\right)^2 \left(3.7 \times 10^{10} \frac{\gamma}{Ci\text{-}sec}\right)$$

$$= 3.7 \times 10^{-6} \frac{\gamma}{cm^2 sec}.$$

The dose is calculated at a height of 1 meter (~ 3 ft) in air:

$$\mu a = \frac{\mu}{\rho} (\rho_{air})(\text{height}) = .077 \frac{cm^2}{gm} \times .00129 \frac{gm}{cm^3} \times 100\ cm = .099$$

$$\phi_{.66} = \frac{S_A}{2} E_1(\mu a) \quad E_1(.099) = 5.$$

$$= \left[\frac{3.7 \times 10^{-6} \frac{\gamma}{cm^2 sec}}{2}\right] \times (5) = 9.25 \times 10^{-6} \frac{\gamma}{cm^2 sec}$$

$$I_o = \phi_{.66} E_{.66} = 6.105 \times 10^{-6} \frac{Mev}{cm^2 sec}$$

$$\text{Dose Rate} = 6.58 \times 10^{-5} \left.\frac{\mu a}{\rho}\right)_{air} I_o = 6.58 \times 10^{-5} \times (.031) \times 7.33 \times 10^{-6}$$

$$= 1.52 \times 10^{-11} \text{ R/hr} = 1.52 \times 10^{-8} \text{ MR/hr}$$

$$\text{Dose Factor} = .869 \sum_{i=1}^{m} A_i\, DR_i P_i \qquad P_i = \frac{I}{I_o} = e^{-\mu x} = e^{-.085(5)} = .654$$

A_i = 93% (only 1 mode in decay energy)

$$DF = .869 \left[.93\ (1.52 \times 10^{-8}).654 \right] = 8.2 \times 10^{-9}\ \text{mrem/hr/pCi/m}^2 =$$

$$8.2\ \frac{\text{Rem/hr}}{\text{Ci/m}^2}$$

This calculation is within 2% of the value obtained in Column 4 of Table 21. Also shown, there are the average gamma energies, the skin dose factors (for reference although no such calculations are done in this study), and the nuclide solubility in cold water. As stated previously, the modified whole body dose factors are used and are one third the value of the original factors.

To obtain the dose rate DR due to ground deposition in rem/day,

$$DR = (\text{Activity density in } \frac{\text{pCi}}{\text{m}^2})(^{1\text{Ci}}/_{10^{12}\text{pCi}})(\text{Dose Factor in } \frac{\text{rem/day}}{\text{Ci/m}^2}) \times (24\ \text{hr/day}).$$

To find the total dose TD over an integrated time from the beginning of exposure at time t=o to some time t then,

$$TD\ (\text{rem}) = \int_0^t DR_o e^{-\lambda t} dt = \frac{DR_o}{\lambda}(1-e^{-\lambda t})$$

where DR_o is the dose rate at t=o in rem/day calculated above and λ is the nuclide decay constant in days^{-1}.

PART IV

THE MODAIREM COMPUTER CODE

Figures 3 and 4 through 4.7 show the basic flow of control between subroutines and a simplified flow diagram for each subroutine.

FIGURE 3

FLOW OF CONTROL

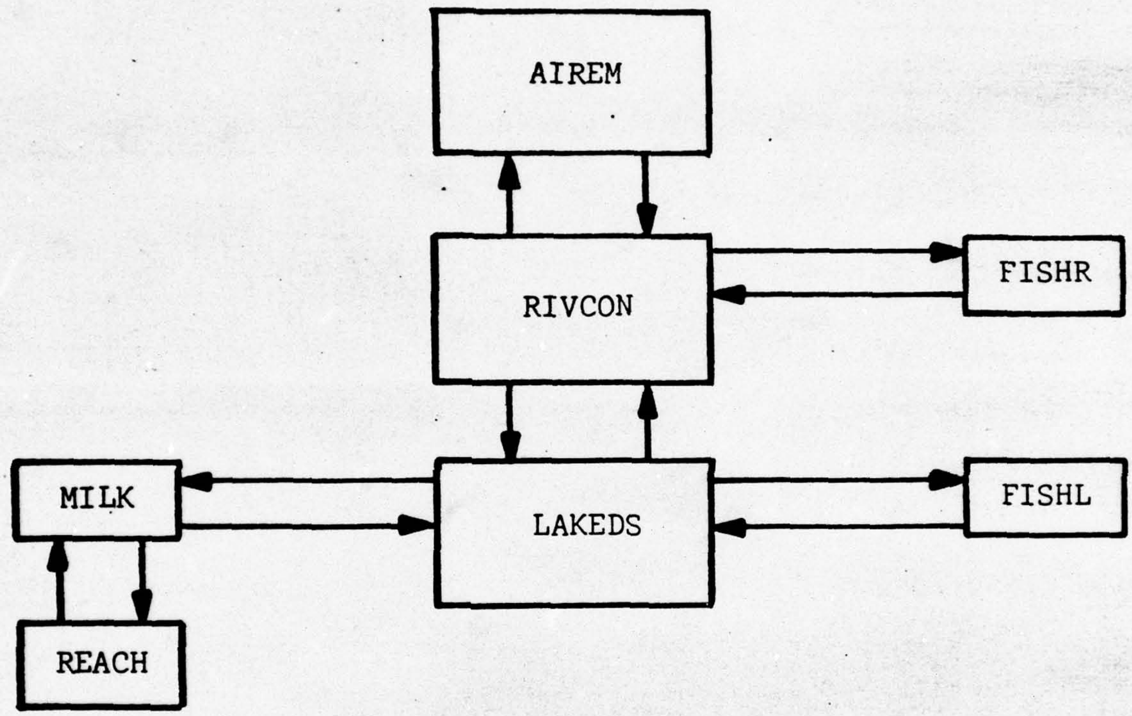


FIGURE 4

SIMPLIFIED MODAIREM FLOW DIAGRAM

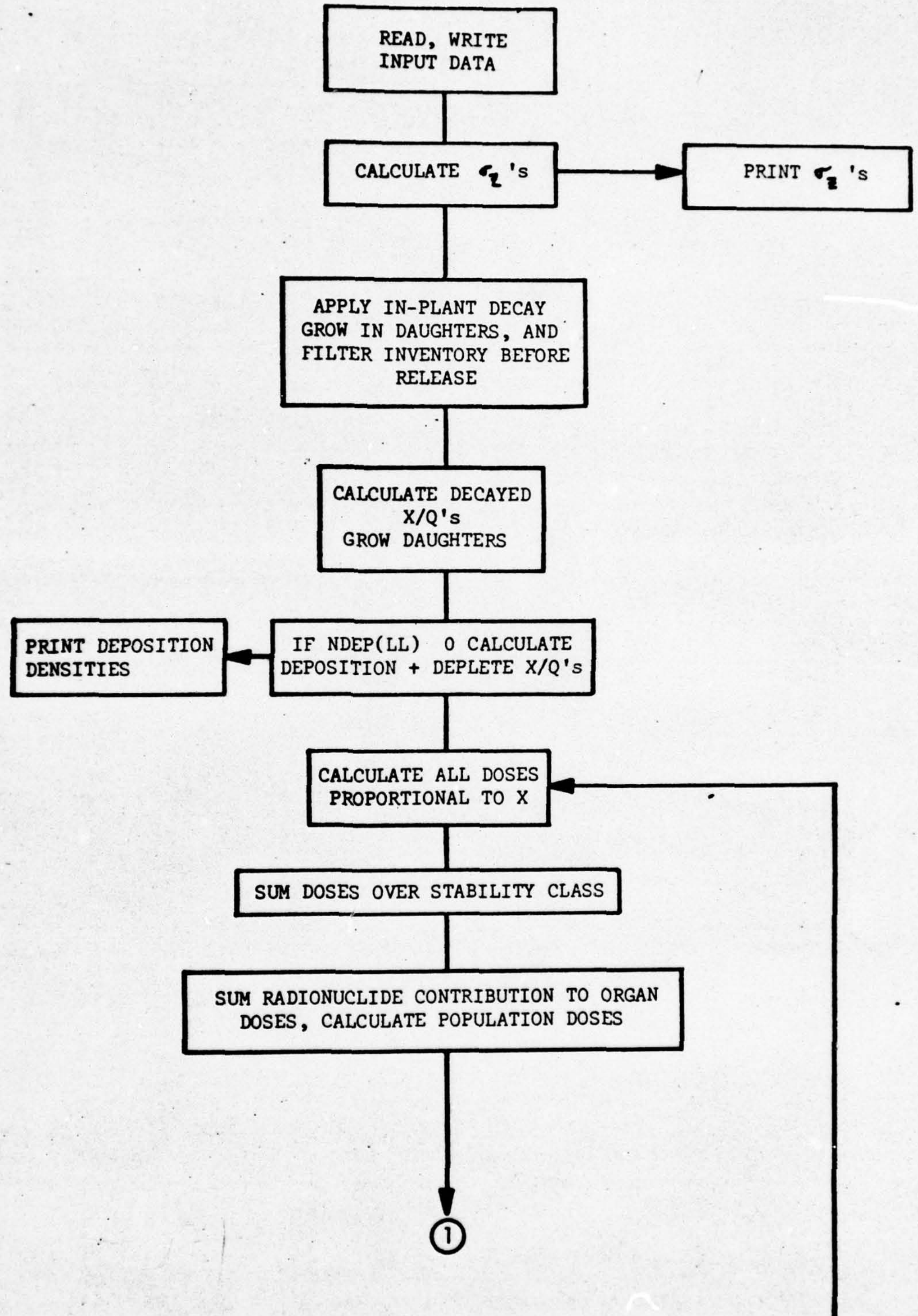


FIGURE 4.1

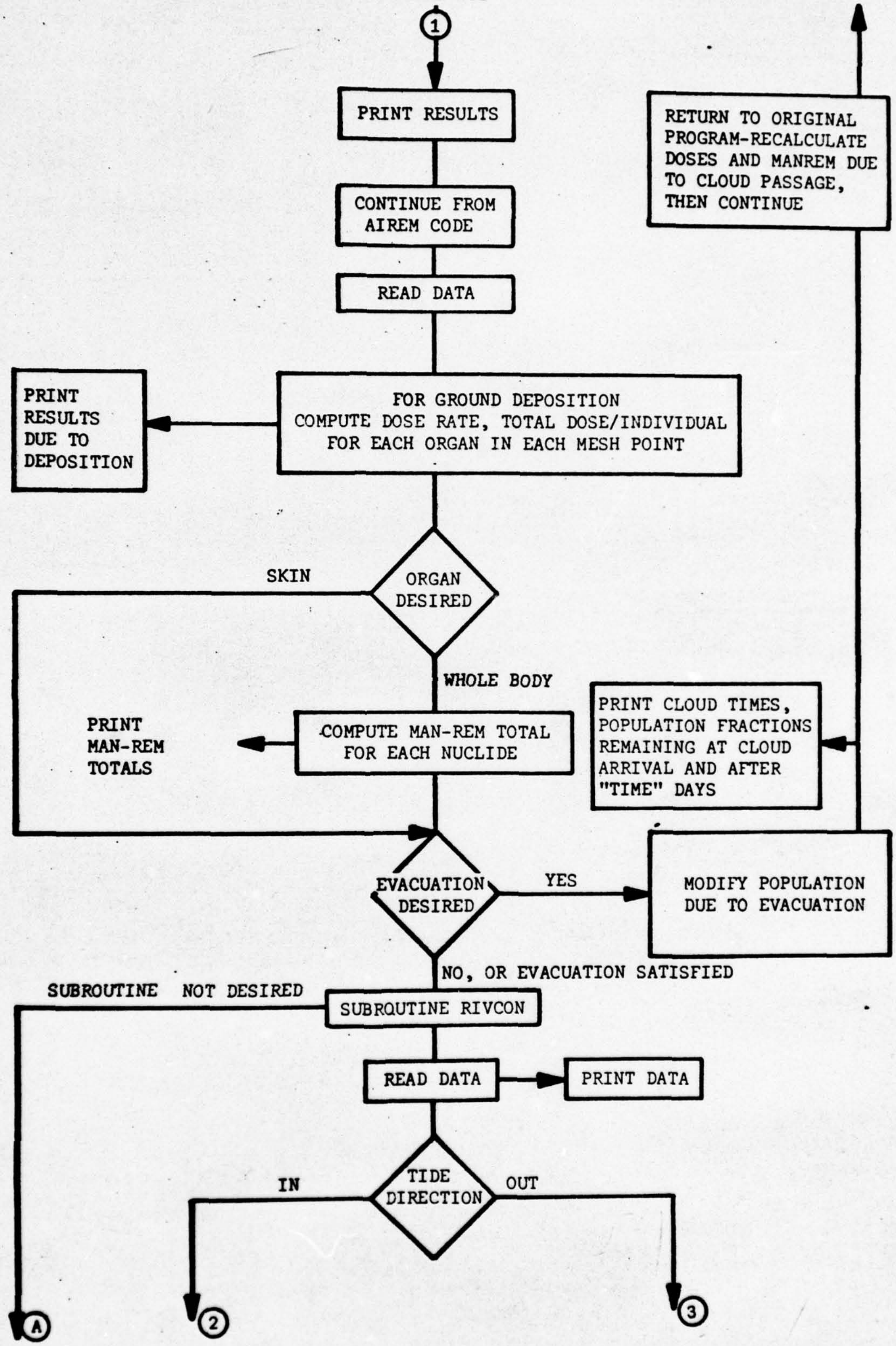

1
PRINT RESULTS
CONTINUE FROM AIREM CODE
READ DATA
RETURN TO ORIGINAL PROGRAM-RECALCULATE DOSES AND MANREM DUE TO CLOUD PASSAGE, THEN CONTINUE
PRINT RESULTS DUE TO DEPOSITION
FOR GROUND DEPOSITION COMPUTE DOSE RATE, TOTAL DOSE/INDIVIDUAL FOR EACH ORGAN IN EACH MESH POINT
SKIN
ORGAN DESIRED
WHOLE BODY
PRINT MAN-REM TOTALS
COMPUTE MAN-REM TOTAL FOR EACH NUCLIDE
PRINT CLOUD TIMES, POPULATION FRACTIONS REMAINING AT CLOUD ARRIVAL AND AFTER "TIME" DAYS
EVACUATION DESIRED
YES
MODIFY POPULATION DUE TO EVACUATION
NO, OR EVACUATION SATISFIED
SUBROUTINE NOT DESIRED
SUBROUTINE RIVCON
READ DATA
PRINT DATA
IN
TIDE DIRECTION
OUT
A
2
3

FIGURE 4.2

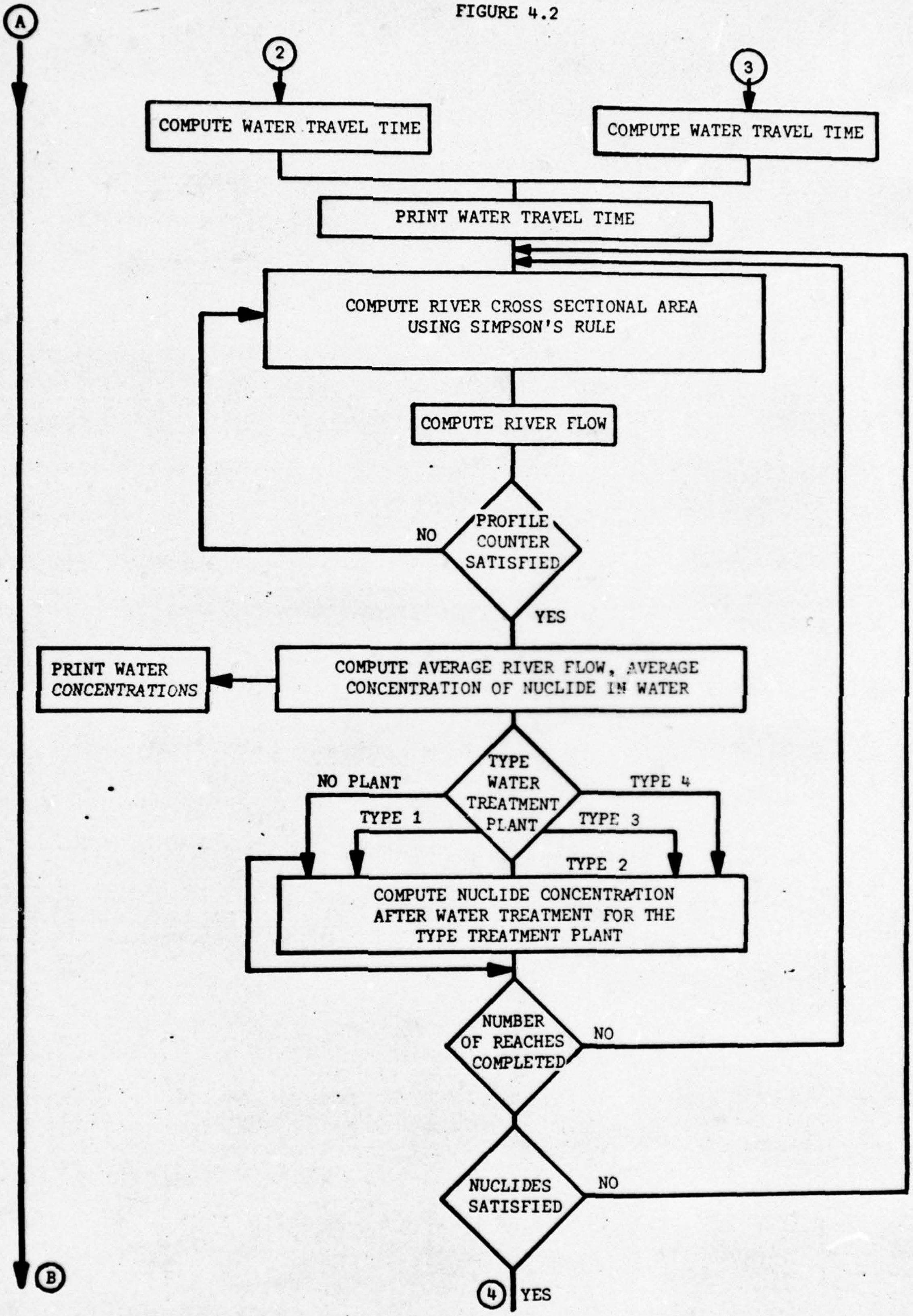
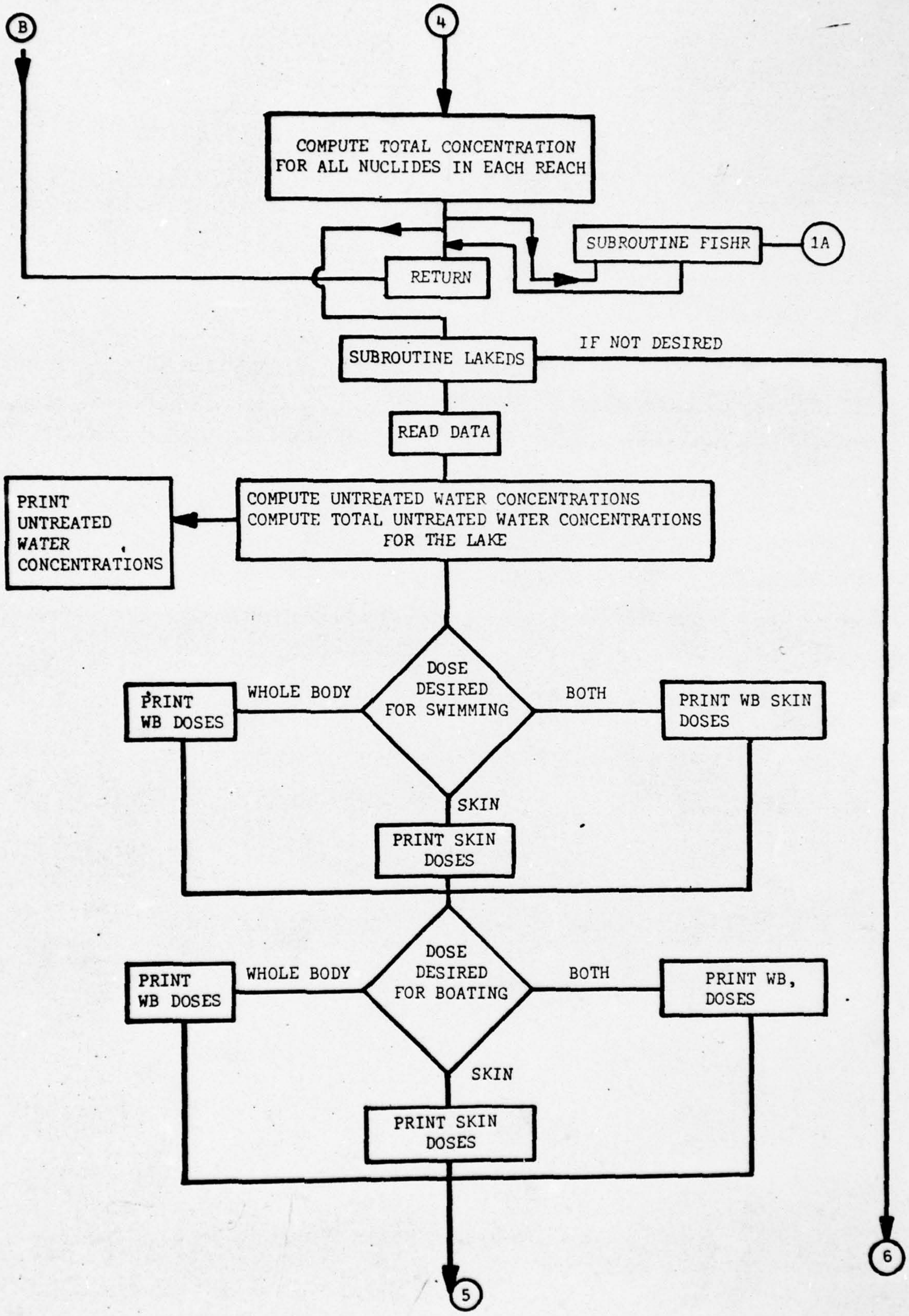

A
2
3
COMPUTE WATER TRAVEL TIME
COMPUTE WATER TRAVEL TIME
PRINT WATER TRAVEL TIME
COMPUTE RIVER CROSS SECTIONAL AREA USING SIMPSON'S RULE
COMPUTE RIVER FLOW
PROFILE COUNTER SATISFIED
NO
YES
PRINT WATER CONCENTRATIONS
COMPUTE AVERAGE RIVER FLOW, AVERAGE CONCENTRATION OF NUCLIDE IN WATER
TYPE WATER TREATMENT PLANT
NO PLANT
TYPE 1
TYPE 2
TYPE 3
TYPE 4
COMPUTE NUCLIDE CONCENTRATION AFTER WATER TREATMENT FOR THE TYPE TREATMENT PLANT
NUMBER OF REACHES COMPLETED
NO
NUCLIDES SATISFIED
NO
B
4
YES

FIGURE 4.3



B
4
COMPUTE TOTAL CONCENTRATION FOR ALL NUCLIDES IN EACH REACH
SUBROUTINE FISHR
1A
RETURN
SUBROUTINE LAKEDS
IF NOT DESIRED
READ DATA
COMPUTE UNTREATED WATER CONCENTRATIONS
COMPUTE TOTAL UNTREATED WATER CONCENTRATIONS FOR THE LAKE
PRINT UNTREATED WATER CONCENTRATIONS
DOSE DESIRED FOR SWIMMING
WHOLE BODY
PRINT WB DOSES
BOTH
PRINT WB SKIN DOSES
SKIN
PRINT SKIN DOSES
DOSE DESIRED FOR BOATING
WHOLE BODY
PRINT WB DOSES
BOTH
PRINT WB, DOSES
SKIN
PRINT SKIN DOSES
5
6

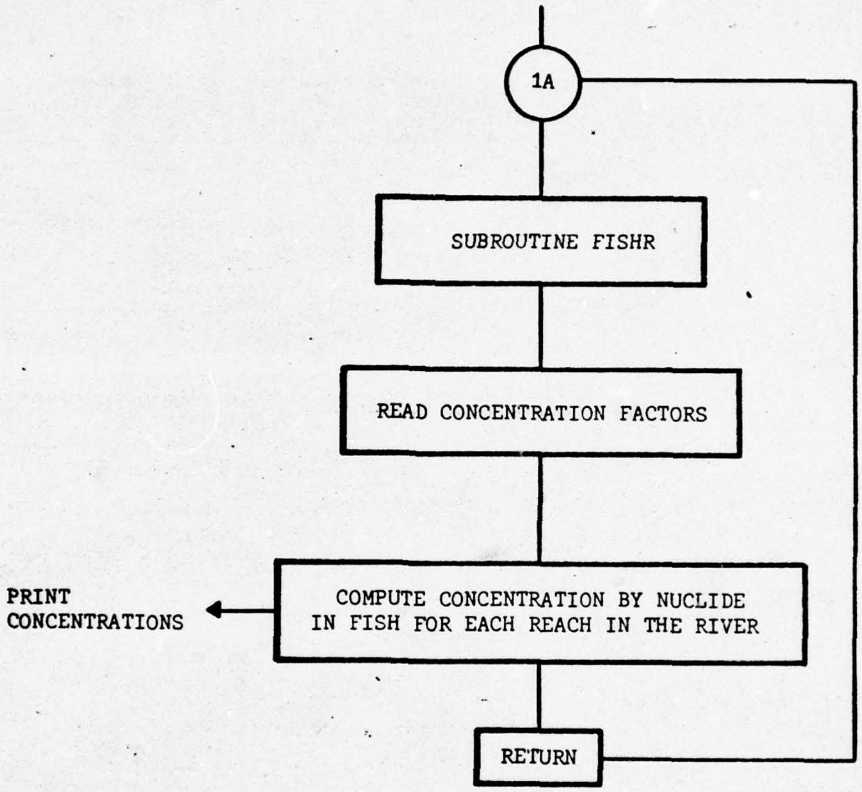

1A
SUBROUTINE FISHR
READ CONCENTRATION FACTORS
COMPUTE CONCENTRATION BY NUCLIDE IN FISH FOR EACH REACH IN THE RIVER
PRINT CONCENTRATIONS
RETURN

FIGURE 4.4

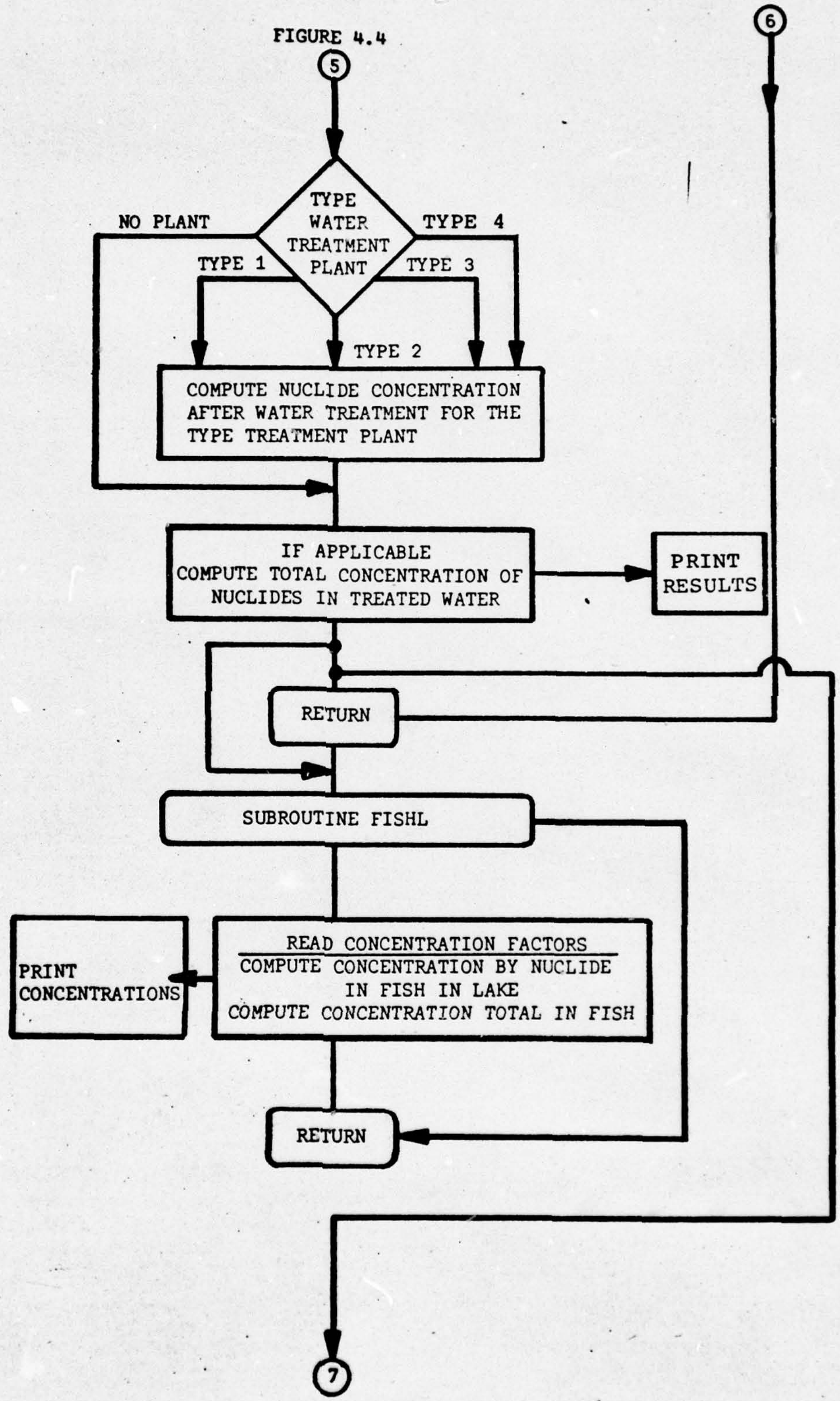

5
6
TYPE WATER TREATMENT PLANT
NO PLANT
TYPE 1
TYPE 2
TYPE 3
TYPE 4
COMPUTE NUCLIDE CONCENTRATION AFTER WATER TREATMENT FOR THE TYPE TREATMENT PLANT
IF APPLICABLE COMPUTE TOTAL CONCENTRATION OF NUCLIDES IN TREATED WATER
PRINT RESULTS
RETURN
SUBROUTINE FISHL
READ CONCENTRATION FACTORS
COMPUTE CONCENTRATION BY NUCLIDE IN FISH IN LAKE
COMPUTE CONCENTRATION TOTAL IN FISH
PRINT CONCENTRATIONS
RETURN
7

FIGURE 4.5

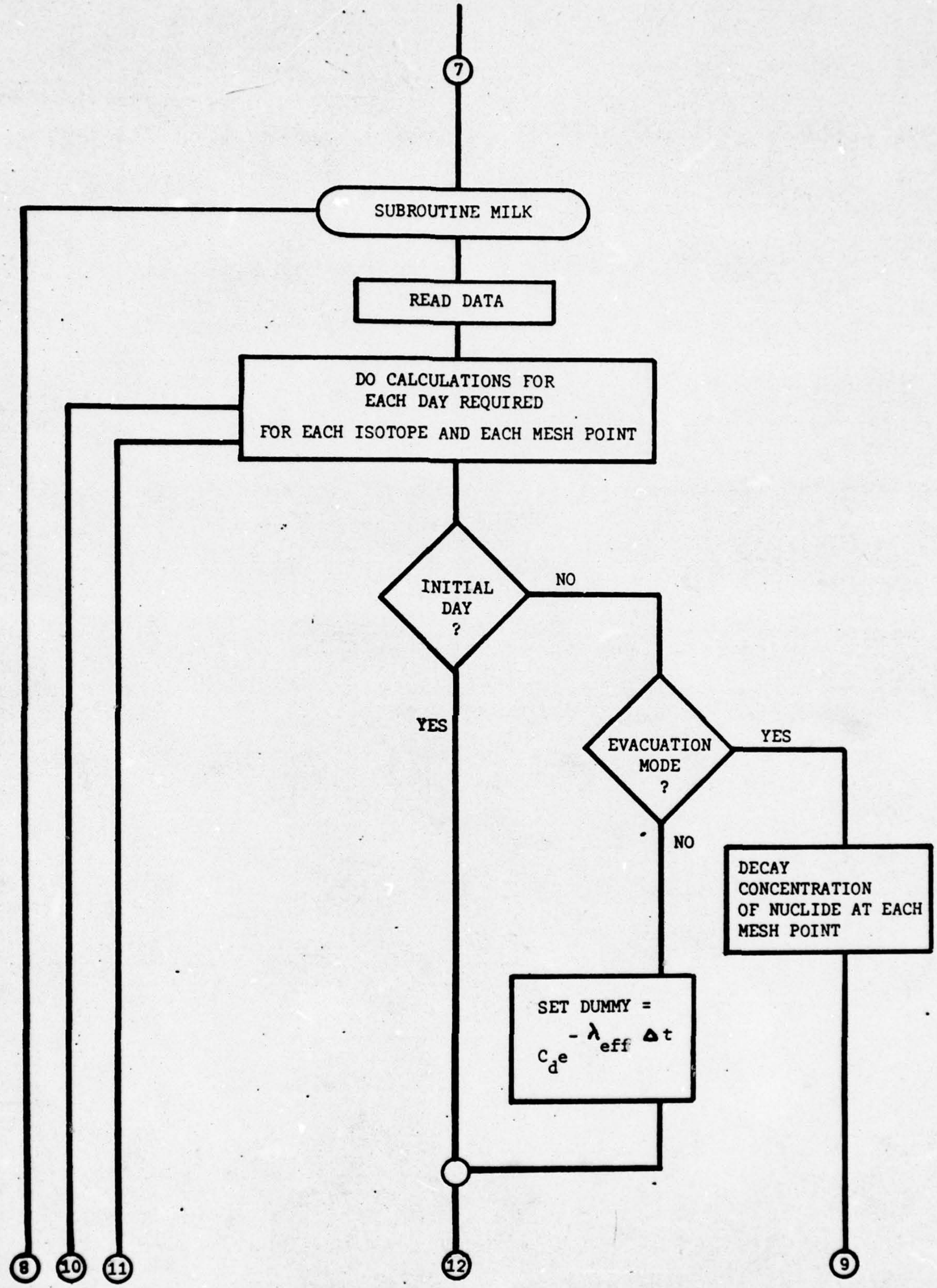

7
SUBROUTINE MILK
READ DATA
DO CALCULATIONS FOR EACH DAY REQUIRED
FOR EACH ISOTOPE AND EACH MESH POINT
INITIAL DAY ?
NO
YES
EVACUATION MODE ?
YES
NO
DECAY CONCENTRATION OF NUCLIDE AT EACH MESH POINT
SET DUMMY = $C_d e^{-\lambda_{eff} \Delta t}$
8
10
11
12
9

FIGURE 4.6

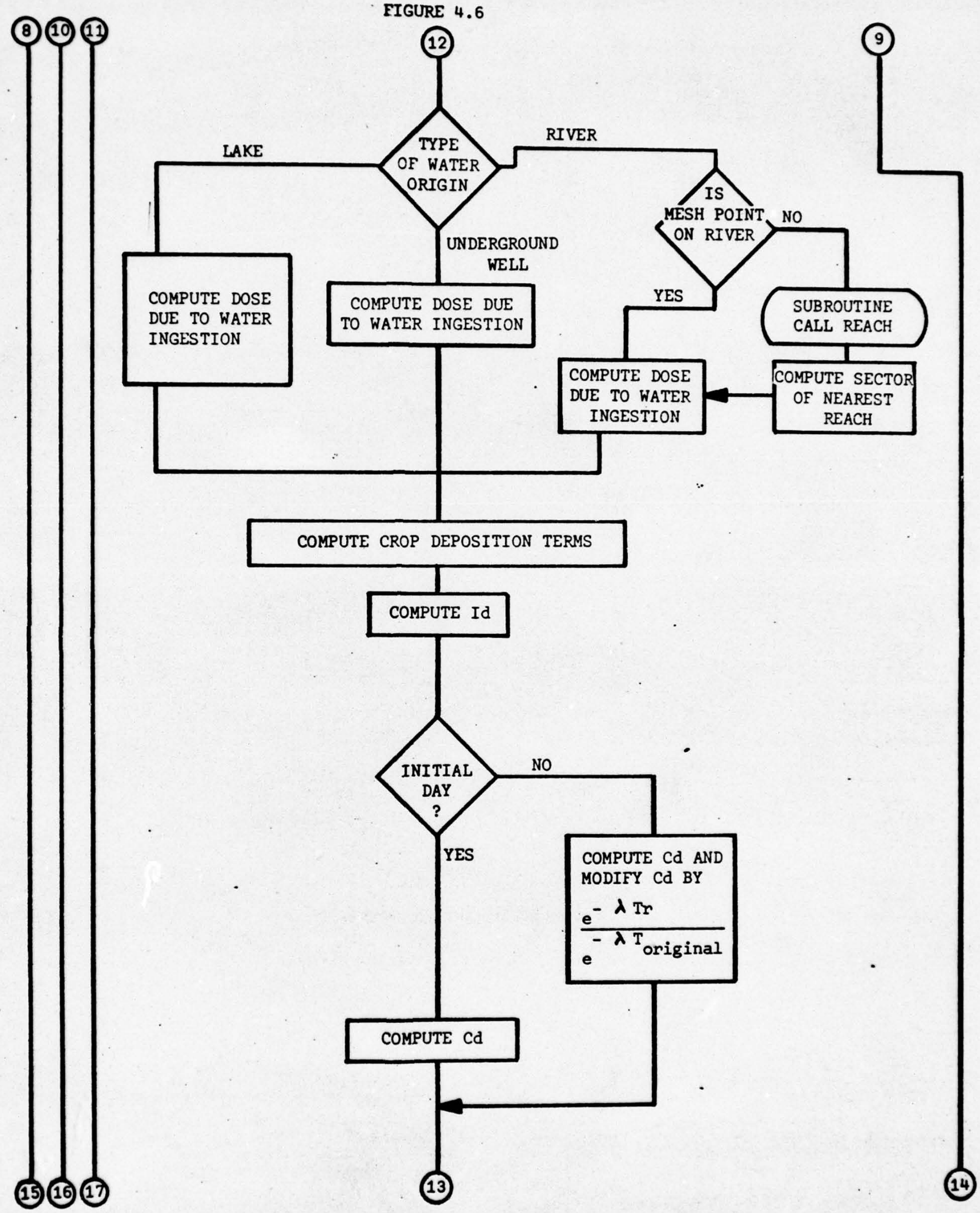
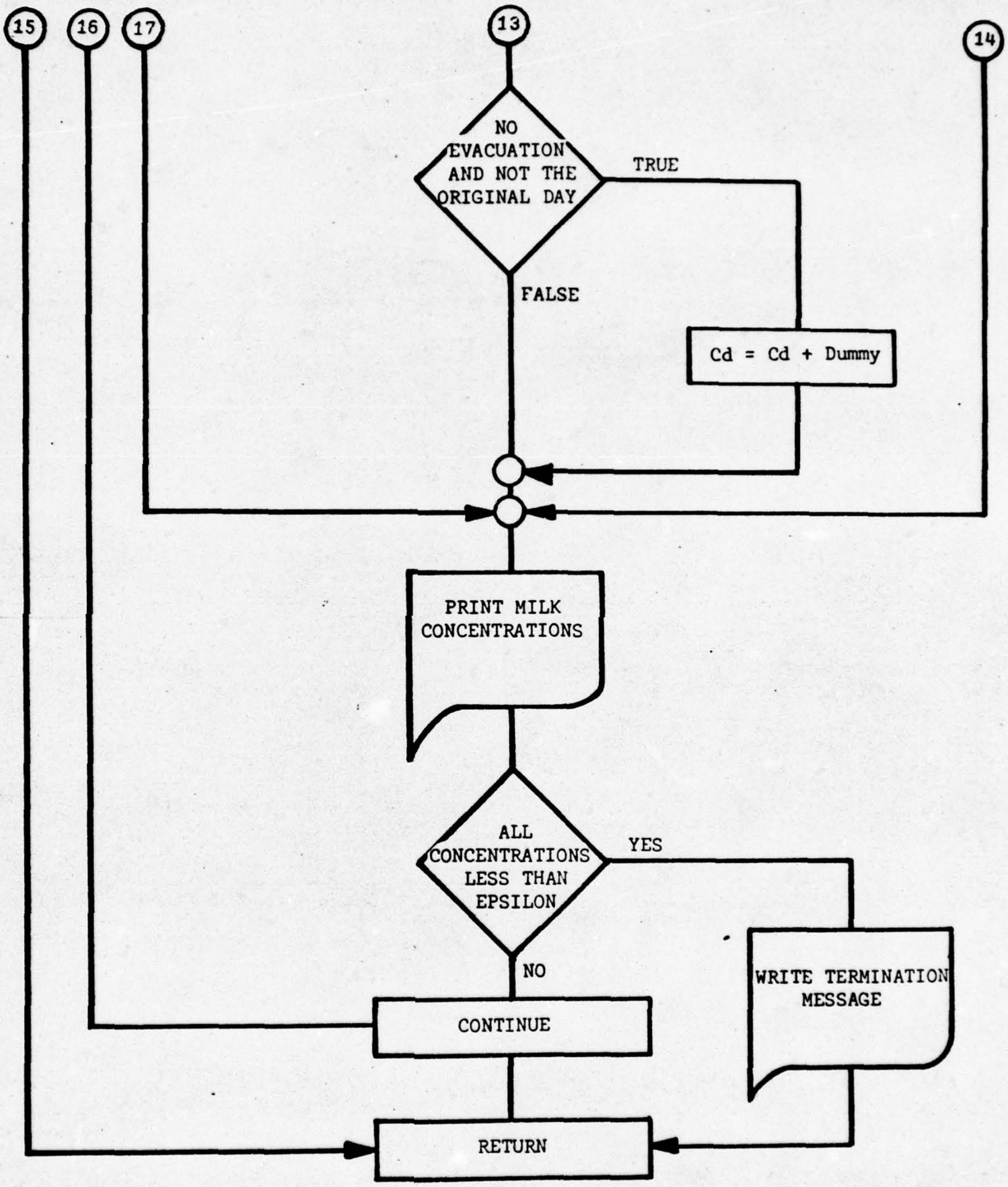

8
10
11
12
9
TYPE OF WATER ORIGIN
LAKE
RIVER
UNDERGROUND WELL
IS MESH POINT ON RIVER
NO
YES
COMPUTE DOSE DUE TO WATER INGESTION
COMPUTE DOSE DUE TO WATER INGESTION
SUBROUTINE CALL REACH
COMPUTE DOSE DUE TO WATER INGESTION
COMPUTE SECTOR OF NEAREST REACH
COMPUTE CROP DEPOSITION TERMS
COMPUTE Id
INITIAL DAY ?
NO
YES
COMPUTE Cd AND MODIFY Cd BY
e- λ Tr / e- λ Toriginal
COMPUTE Cd
15
16
17
13
14

FIGURE 4.7


15
16
17
13
14
NO EVACUATION AND NOT THE ORIGINAL DAY
TRUE
FALSE
Cd = Cd + Dummy
PRINT MILK CONCENTRATIONS
ALL CONCENTRATIONS LESS THAN EPSILON
YES
NO
WRITE TERMINATION MESSAGE
CONTINUE
RETURN

A. Definitions

There are many new variables used in addition to the original AIREM program. For purposes of clarity, definitions of the more important terms are given in Tables 7 through 11.

B. Initial Data

The initial data used was entered according to Reference 10 and the definitions are as listed.

Number of sectors	16
Number of stability classes	6
Number of radii	12
Number of isotopes	19 + 19 + 7 =45
Effective release height	31 m[13]
SIGMAX	742 m[13]
In-plant holdup time	0
Rainfall fraction	0 or 1
Washout factor	.0002[10]
Wind frequencies by stability class (%)	Table 2
Wind speeds by stability class	Table 3
Annular ring population (yr 1990)	Table 4
Midpoint, lower, and upper radii	Table 5
Cloud dose model	semi-infinite
Source strengths	Table 6

C. Additional Data Required

To obtain whole body or skin doses due to deposition of radionuclide contamination on the ground, and to use one of the two possible modes of evacuation, 41 data cards are necessary for 20 isotopes. Ground deposition dose factors for whole body or skin for each nuclide are required in units of rem/hr per Ci/m^2, as are decay factors in $days^{-1}$. In addition, the evacuation parameters must be given. Further detail is provided in Figure 5.

Data required for subroutine RIVCON will vary considerably according to the detailed data available for the river under study. Needed are ebb and flow velocities and durations, reach data which profiles the river at various locations, nuclide solubilities in cold water and dissolved nuclide fractions which can pass through the various type water treatment facilities available. Information as to the river segments (reaches) and their relative location to the 16 compass sector, 12 radii map is also needed. Specifics are provided in Figure 6.

Following RIVCON is subroutine FISHR which requires one data card per isotope to provide nuclide concentration factors for fresh water fish. Subroutine LAKEDS requires 24 data cards for 20 isotopes and the entering of swimming and/or boating dose factors, lake surface areas and volumes, its mesh point location and water treatment facility type used. Details on data card production and their order are given in Figure 7. Subroutine FISHL uses the data entered in FISHR for computation so no additional cards are necessary. Subroutine MILK requires local or average data on crop yields, drinking water sources if available, forage crop concentration factors in pCi/kg of

fresh plant per pCi/kg of dry soil for each nuclide, and the coefficient of transfer of each nuclide from the diet to milk in pCi/l per pCi/day. Both a biological half-life on the crop and in the cow must be given. Figure 8 lists the pertinent data required. Subroutine REACH requires no additional data.

FIGURE 5

DATA REQUIRED-ADDITION TO MAIN PROGRAM

After five blank cards in AIREM (semi-infinite cloud only used):

Card Sequence	Columns	Title	Format
L Cards[1]	1-10	Ground deposition dose factors (Rem/hr/Ci/m^2) for WB or skin for the nuclide.	F10.4
	11-25	Decay factor in $days^{-1}$ for the nuclide.	E15.3
	26-30	Integrated time of exposure to contaminatd ground (days).	F5.1
	31-35	Type Dose, 0= whole body, 1 = skin	I5
1 Card	1-10	Fraction of population unaffected by evacuation	F10.2
	11-20	Evacuation rate ($days^{-1}$)	F10.2
	21-30	Time lag between interpretation of data and order to evacuate	F10.2
	31-40	Time between awareness of core melt and leakage.	F10.2
	41-45	Evacuation mode -1 = Evacuation outside furthest sector. 0 = no evacuation. 1 = Evacuation outside midway radius being considered.	I5

If evacuation = 1 or -1 repeat L[1] cards.

FIGURE 6

DATA REQUIRED SUBROUTINE RIVCON

Card Sequence	Columns	Title	Format
1 Card	1-10	Delay time (days) before computing water concentrations. IF = 0., then subroutine RIVDOS is not used.	F10.0
1 Card	1-5	Time (hrs) the tide flows out.	F5.1
	6-10	Time (hrs) the tide flows in.	F5.1
	11-15	Water velocity (mi/hr) with the tide flowing out.	F5.1
	16-20	Water velocity (mi/hr) with the tide flowing in.	F5.1
	21-25	Tide direction at the time of accident. 0 = out 1 = in	I5
	26-30	Number of reaches (19 Max).	I5
	31-35	Number of depths/cross sectional profile at equidistant intervals (3, 5, 7, 9 or 11 only).	I5
	36-40	Number of profiles/reach (20 Max).	I5
L Cards	1-15	Plant discharge (pCi/sec)	E15.6
	16-25	Nuclide solubility in cold water. 0. = insoluble .5 = slightly soluble or decomposes 1.0 = soluble or unknown	F10.2
	26 -35	Dissolved nuclide fraction passing water treatment facilities of Type 3 or 4	F10.2
IIRECH Cards	1-10	Length of reach (miles)	F10.3
	11-25	Surface area (ft^2) of river in the reach.	E15.6
	26-30	Water treatment facility status 0 = no facility 1 = class 1 facility 2 = class 2 facility 3 = class 3 facility 4 = class 4 facility	I5
IIRECH x NPROF cards	1-6	River Width (ft).	F6.1
	7-12	Equidistant river depths (ft) 6 columns each, 3, 5, 7, 9 or 11 depths.	F6.1

DO ALL PROFILES FOR 1 REACH, THEN NEXT REACH.

Card Sequence	Columns	Title	Format
IIRECH cards	1-5	Reach number	
	6-10	MM mesh point location	
	11-15	II of the reach	I5

FIGURE 7

DATA REQUIRED-SUBROUTINE LAKEDS

Card Sequence	Columns	Title	Format
1 Card	1-5	Setup indicator number of LAKES 1 = run LAKEDS x times 0 - skip LAKEDS	I5
		(IF 0 - no other cards required)	F10.1
1 Card	1-15	Lake surface area (ft^2)	E15.7
	16-25	Time spent swimming (hrs)	F10.1
	26-35	Time spent boating (hrs)	F10.1
	36-50	Lake volume (gallons)	E15.7
1 Card	1-5	Desired doses 0 = whole body only 1 = skin dose only 2 = WB and skin doses	I5
	6-13	Name of lake	2A4
L Cards	1-15	Whole body dose factor due to swimming in the lake.	E15.7
	16-30	Skin dose factor due to swimming in the lake.	E15.7
1 Card	1-5	Radius of majority of the lake	I5
	6-10	Sector of majority of the lake	I5
	11-15	Water treatment facility used (same as in RIVCON).	I5

IF MORE THAN ONE LAKE IS USED ENTER 1 LAKEDS DATA SET, THAN CORRESPONDING FISHL DATA, THEN NEXT LAKEDS DATA SET.

FIGURE 8

DATA REQUIRED-SUBROUTINE MILK

Card Sequence	Columns	Title	Format
1	1-5	Number of mesh points not using wells -1 = skip subroutine	I5
1	1-10	Forage ingestion by cow (Kg/day)	F10.2
	11-20	Deposition retension factor	F10.2
	21-30	Forage crop yield (Kg/m^2)	F10.2
1	1-10	Ingestion of drinking water by dairy cow (L/day)	F10.2
	11-20	Typical drinking trough size (ft^2)	F10.2
	21-30	Typical trough capacity (gal)	F10.2
NUMBER	1-5	Drinking water type 1 = river 2 = lake	I5
	6-10	Radius of drinking water source	I5
	11-15	Sector of drinking water source	I5
	16-20	Water treatment facility type	I5
1	1-5	Maximum number of days for which milk calculations are to be calculated	I5
	6-10	Increments (days) between successive concentration calculations	I5
1	1-5	Evacuation mode/use of uncontaminated feed: 0 = no evacuation 1 = evacuation after 1 day	I5
	6-15	Biological half-life (days) of nuclide on forage crop	F10.2
L	1-10	Forage crop concentration factor (B) $\frac{\text{pCi/Kg fresh plant}}{\text{pCi/Kg dry soil}}$	E10.2
	11-15	Coefficient of transfer S_d from diet to milk (pCi/l per pCi/day)	E15.1
1	1-10	Nuclide half life in the dairy cow	F10.2

Subroutine RIVCON

A partial listing of the initial data used in this subroutine is:

Delay time	1 day
Time of ebb flow (hrs)	6.0
Time of flow tide (hrs)	5.9
Average water velocity at ebb tide (mi/hr)	2.1
Average water velocity at flow tide (mi/hr)	1.5
Tide direction at accident time	FLOW
Number of reaches	19
Depths/profile	5
Profiles/reach	10
Plant discharge (pCi/sec)	0.
Nuclide solubility in cold water	Table 21
Nuclide fraction passing water treatment facilities	Table 22
Reach length, surface area, water treatment facility type, reach number, and mesh point locations of the reaches	Table 23

Subroutine LAKEDS

Thirteen lakes are examined in this study and whole body doses only are calculated. These lakes with their associated drinking water facility data is given in Table 24. Water submersion dose factors used are listed in Table 25.

Subroutine FISHR and FISHL

The values used in subroutines FISHR and FISHL for fresh water fish concentration factors are listed in Table 31.

Subroutine MILK

In this study, 18 mesh points using other than underground well water were examined. The cow is assumed to ingest 65 kg of forage per day, and the fraction of deposition retained by the forage crop is taken as .25. Also the forage crop yield is assumed 1.8 kg/m^2. Milk concentrations are computed generally for 60 days in increments of 10 days and generally for the case of no evacuation. The biological half-life of the forage crop on the ground is 14 days and in the cow, it is assumed to be two days (an overly conservative estimate for the cow of .5 days yields concentrations of 10-20% higher than for two days). Table 32 lists the concentration factors (B) of various isotopes on the forage crop and the coefficients of transfer of the various nuclides from the cow's diet to the milk.

PART V

RESULTS

Typical values of radioactivity are 1.873×10^{8} Curies deposited in 490 square miles (50 mile radius), specifically in one wind sector of 22½ degrees and 31 square miles which represents approximately 20% of the total Curies released in the accident.

A. Water Concentrations and Resultant Doses

Subroutines RIVCON and LAKEDS give nuclide concentrations for the various nuclides in pCi/l before and after water treatment. The calculations below are for treated water in Alcove Reservoir after northerly winds, however, the same methods can be used in any of the affected locations. The computed nuclide concentrations are listed in Column 2 of Table 27. These concentrations are converted to approximate doses with the use of the equation,[26]

$$D = \frac{AfET_e}{m} \left(1 - \exp\left(\frac{-1.26 \times 10^{4}}{T_e}\right)\right)\left(\frac{1.6 \times 10^{-6} \times 3.2 \times 10^{15}}{.693 \times 10^{2}}\right) \text{ rem}$$

where D = the total dose; f = the fractional uptake to the organ of interest by ingestion; E= the effective decay energy; T_e = the effective half-time of the nuclide in the organ of interest; m = the mass of the organ of interest in grams; 1.6×10^{-6} = erg/Mev; 3.2×10^{15} = disintegrations/day per Ci; $.693 \times 10^{2}$ = erg/gm/rad; A = 1 to calculate rem per Curie ingested. For example, using the values of E, T_e, m, and f from ICRP-II the dose to the thyroid due to the ingestion of one liter of contaminated water due to ^{131}I is,

$$D_{{}^{131}I_{THY}} = \left(1 \frac{\text{rem}}{\text{Ci}}\right)(.3)(.23)(7.6)\left(1 - \exp\left(\frac{-1.26 \times 10^{4}}{7.6}\right)\right)\left(\frac{1.6 \times 10^{-6} \times 3.2 \times 10^{15}}{.693 \times 10^{2}}\right)$$

$$= 1.94 \times 10^{6} \text{ rem/Ci}$$

This is done for each nuclide for each organ of interest, and multiplying these dose factors times the concentrations yields the values in Columns 6 and 7 of Table 27. Although the results are displayed only for Alcove Reservoir, the same results can be found from the data for Basic Reservoir, Lakes near Kingston, Saugerties, Cooper, Staatsburg, Hollister, Churchtown, Coxsackie, Potuck Lake, Onteora Pond, Lake Forest and Ashokan Reservoir when the winds blow in the appropriate direction.

B. Radionuclide Concentrations in Fish

The individual and total radionuclide inventory ingested by an average fish, both in the various river locations and in the major lakes was calculated using the concentration factors as previously listed. Total concentrations as high as 3.1 Ci/Kg were recorded. It is probable that this level of radioactive material will not actually be ingested for two reasons. First, there could be rapid death of the fish depending on the nuclides ingested and the resultant total dose received, and second, the assumption of one fixed concentration factor will not be valid when extrapolated to these large values. The uptake of these nuclides will vary in response to environmental changes and in response to previously ingested levels.

C. Milk Concentrations

The major assumption in producing the results shown in Tables 28 and 29 is that the cows live and produce the milk from which the concentrations are determined. Because the milk concentration equations are semi-empirical, they provide only an estimate of concentration at each

period of time, although the values for ^{131}I, ^{89}Sr, and ^{90}Sr fit other specific equation reasonably well. The initial concentrations for one day are overly conservative but agree closely with observed data in Reference 22 for the above three nuclides by 11 days. Comparison of the two tables shows the value of evacuation of the dairy cows, or more practically, changing to uncontaminated feed. Converting from concentrations to doses due to ingestion of one liter of milk are accomplished as for water.

D. Lung Inhalation Dose

Lung doses to an individual due to inhalation range from 22,000 rem at ½ mile to 39 rem at 47½ miles in the south-southwesterly direction from 25,200 rem to 47 rem to the west, and 17,100 to 36 rem to the north. Relative doses between sectors are as with others reported in this study and can be seen in Table 16. The man-rem totals to the lung are shown in Table 17. The nuclides which contribute most to the man-rem dosage are:

^{106}Ru	18%
^{103}Ru	15%
^{132}Te	14%
^{131}I	13%
^{140}Ba	10%
^{99}Mo	8%
^{133}I	6%

These nuclides comprise 84% of the total dose integrated over 30 days.

E. Gastrointestinal Tract Dose Due To Inhalation

Gastrointestinal doses to an individual due to inhalation vary from 48,600 rem at one-half mile in the south-southwesterly direction to 32 rem at 47½ miles. To the west, the doses run from 48,600 rem at one-half mile to 36 rem at 47½ miles. To the north 15,900 rem to 31 rem are calculated, and in the direction of least consequence, southwest, from 14,600 to 29 rem doses are found for each person. Specifics can be found in Table 14. The gastrointestinal man-rem totals are displayed for each direction in Table 15. Five nuclides contribute 76% of the total GI dose with:

^{132}Te	30%
^{99}Mo	22%
^{103}Ru	10%
^{106}Ru	9%
^{140}Ba	5%

These doses are integrated over a 50 year period.

F. Thyroid Inhalation Dose

Thyroid doses to an individual due to inhalation of the nuclides in this study vary from 300,000 rem at ½ mile south southwesterly to 4100 rem at 15 miles to 660 rem at 47½ miles. In the westerly direction where the highest individual doses occur, the ½ mile dose is 710,000 rem, 4000 rem at 22½ miles and 1000 rem at 47½ miles. The smallest doses are in the south-southeasterly direction with the doses in the northerly direction towards Albany slightly larger as can be seen in Table 12. The thyroid man-rem doses are listed in Table 13. In this case, iodine contributes 97% of the dose to the thyroid with ^{131}I

contributing 60%, ^{133}I, 30%, and ^{135}I contributing 7% of the dose. The integration time used is assumed essentially infinite since a 50 year integration time is used.

G. Whole Body Inhalation Dose

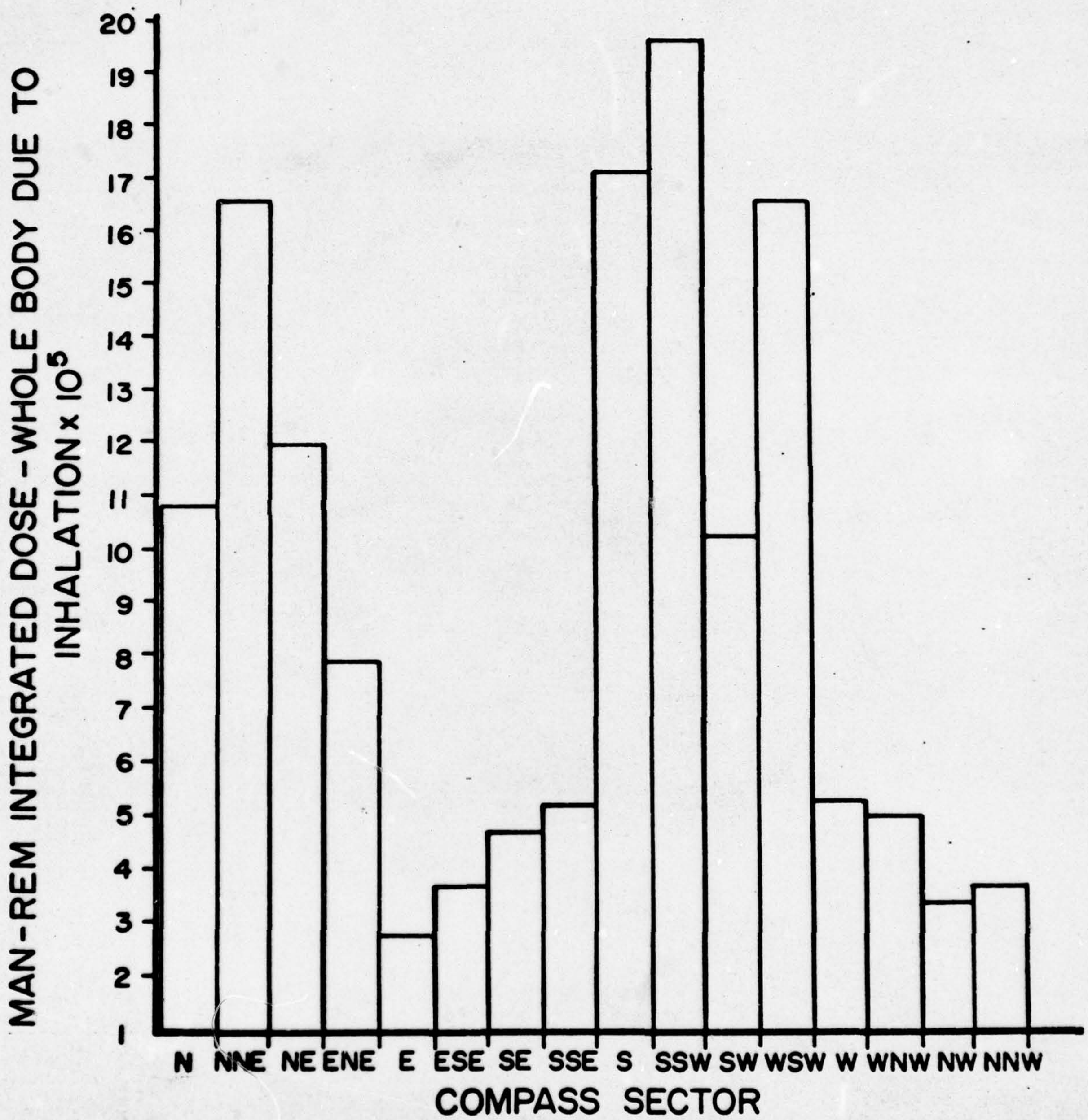
Individual whole body doses due to inhalation of 45 nuclides in this study vary from 1286 rem in the south-southwesterly direction where the maximum rem dose occurs at one-half mile from the site, dropping sharply to 100 rem at 4½ miles and to 16 rem at 15 miles. The highest dosage to an individual occurs in the westerly direction from a maximum of 3123 rem at one-half mile to 90 rem at 7½ miles to 13 rem at 22½ miles. In the northerly direction the dose is 990 rem at ½ mile, 13 rem at 15 miles, and approximately 2 rem at Albany. (See Figures 9 and 10.) Approximately three-quarters of the dose can be attributed to the following nuclides:

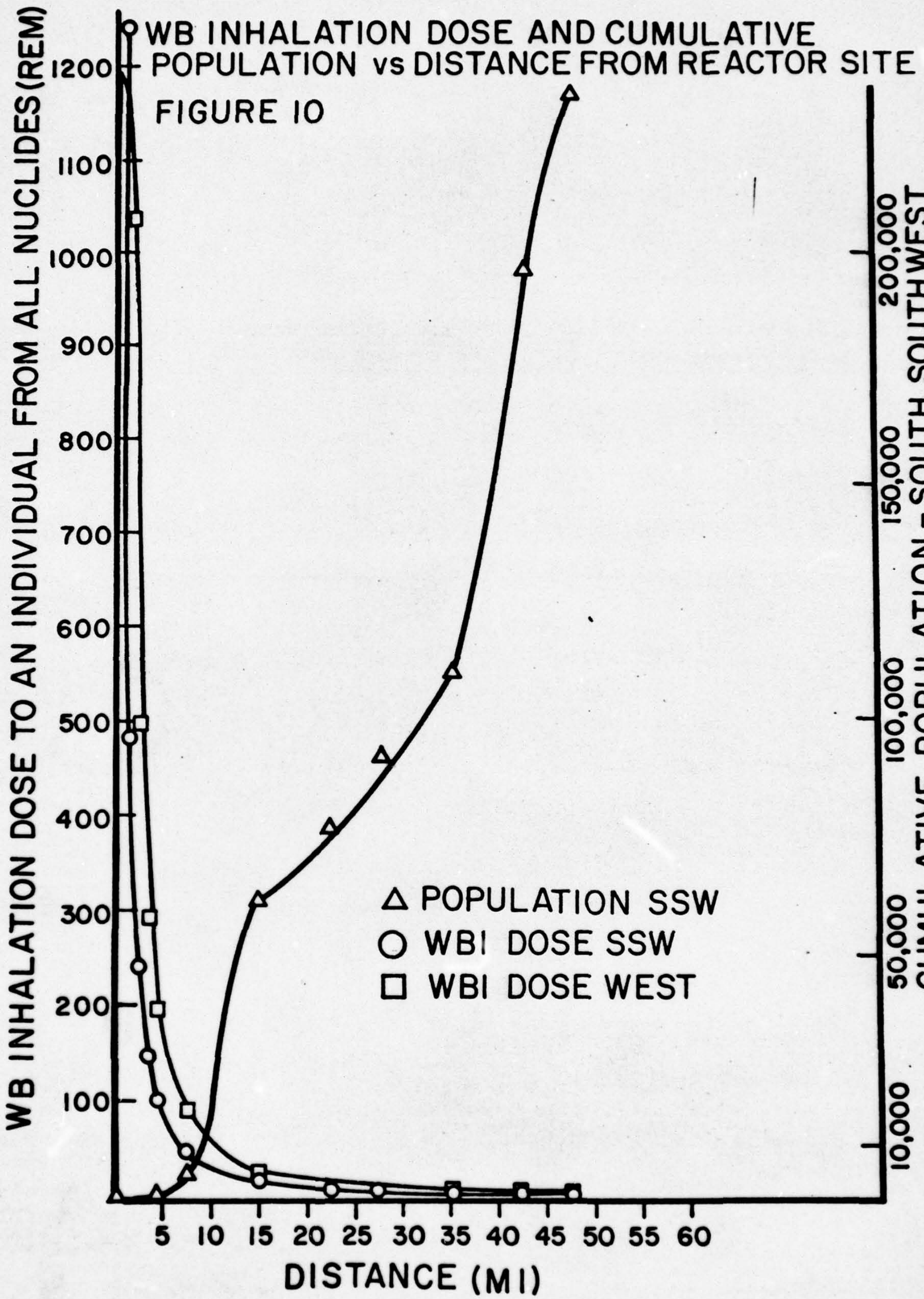
^{131}I	25%
^{132}Te	15%
^{133}I	11%
^{140}Ba	10%
^{99}Mo	7%
^{103}Ru	5%

H. Whole Body Cloud Submersion Dose

Whole body doses to an individual due to radiation from a passing nuclide cloud vary from 760 rem at ½ mile to .61 rem at 47½ miles in the south-southwesterly direction, from 1730 to .57 rem to the west

FIGURE 9
POPULATION DOSE vs. COMPASS SECTOR





WB INHALATION DOSE AND CUMULATIVE
POPULATION vs DISTANCE FROM REACTOR SITE
FIGURE 10
WB INHALATION DOSE TO AN INDIVIDUAL FROM ALL NUCLIDES (REM)
1200
1100
1000
900
800
700
600
500
400
300
200
100
5
10
15
20
25
30
35
40
45
50
55
60
DISTANCE (MI)
CUMULATIVE POPULATION - SOUTH SOUTHWEST
10,000
50,000
100,000
150,000
200,000
△ POPULATION SSW
○ WBI DOSE SSW
□ WBI DOSE WEST

and 580 to .62 rem to the north. Doses in selected directions can be seen in Table 18. Man-rem totals can be compared in Table 19. The iodines contribute 75% of the man-rem dose in this mode with ^{135}I contributing 30%, ^{132}I at 19%, ^{133}I at 12%, ^{134}I at 9%, and ^{131}I at 5%.

I. Whole Body Ground Deposition Dose

Whole body doses due to standing on contaminated ground for one day immediately following the reactor accident are calculated and displayed in Figure 11. The man-rem dosage calculated shows the same general shape as Figure 1 for whole body inhalation. The variation in individual dose can be seen in Table 20 which shows the factor of 1000 decreases in dose at approximately 50 miles from initial ½ mile dose values, and the man-rem dosage by direction are listed in Table 20A.

Five nuclides contribute 88% of the total ground deposition dose:

^{103}Ru	40%
^{106}Ru	15%
^{137}Cs	17%
^{134}Cs	12%
^{131}I	4%

J. The Effect of Meandering Winds on Dose

The iodine-131 whole body dose is shown in Figure 12. The second column shows the dose due to winds blowing into the north. The third column shows the doses due to the winds blowing into the two directions shown. The doses may be higher or lower than the average based on the

FIGURE 11

POPULATION DOSE (GROUND DEPOSITION) vs COMPASS SECTOR

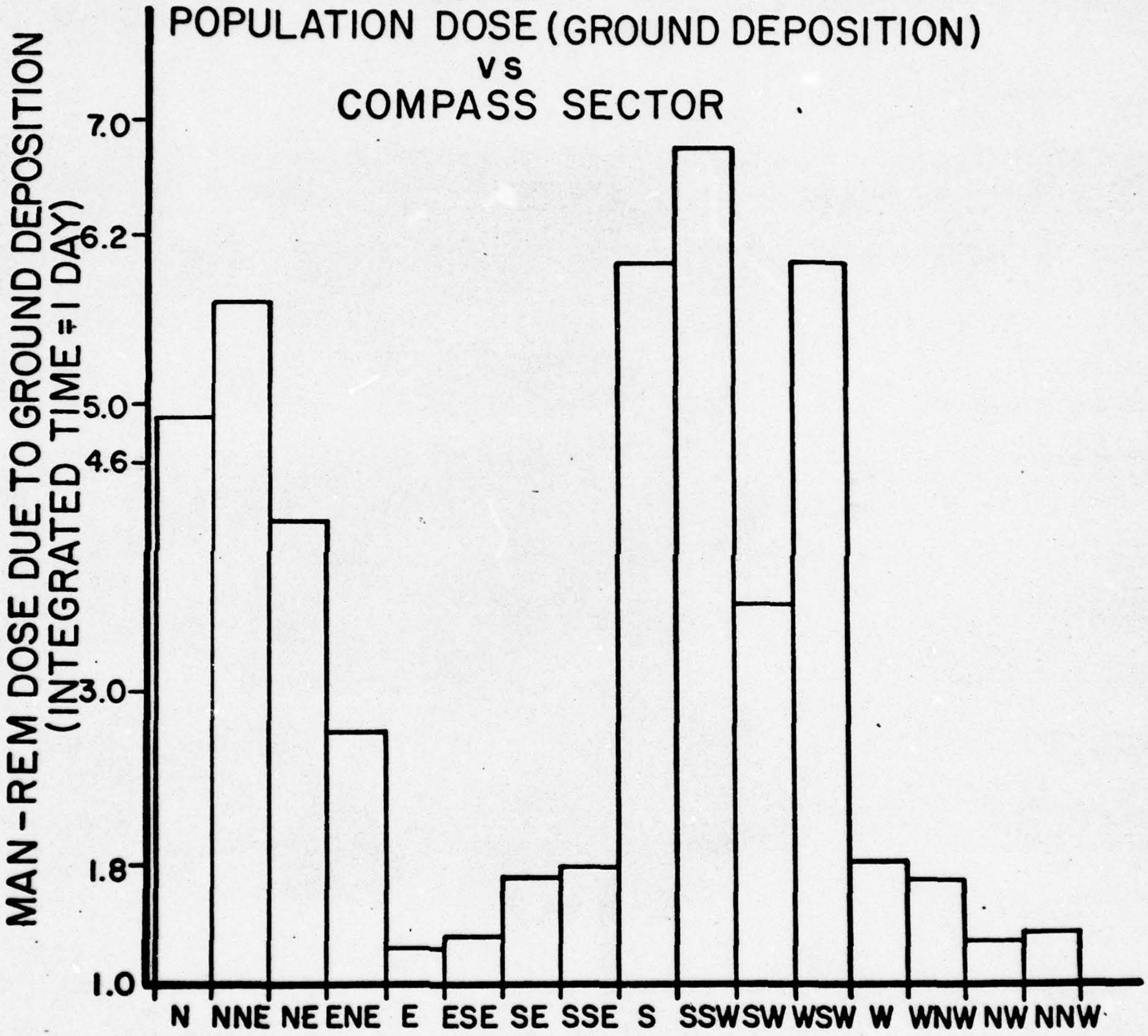


Figure 12

Iodine 131 Dose (Rem) vs. Wind Variation

Distance	North	North through North-Northeast	North through East
½	212.00	110.00	54.60
1½	79.50	44.00	22.40
2½	39.90	22.50	11.60
3½	24.70	14.00	7.16
4½	17.20	9.80	5.02
7½	8.26	4.70	2.42
15	3.05	1.75	.89
22½	1.68	.97	.48
27½	1.26	.72	.36
35	.90	.52	.25
42½	.68	.39	.19
47½	.58	.33	.16
		13% more dispersed in twice the area of one sector	42% more Curies dispersed in 5 times the area of one sector

Whole body dose due to ground deposition.

weighted average of the fractional length of time the wind blows in each sector. The fourth column is for winds blowing from north to east with all wind sectors having equal probabilities of occurrence and all stability classes having the same probability of occurrence. This figure shows the decreasing dose with increased meandering of the wind since slightly more radioactivity is spread over much larger areas. This does not mean, however, that there will necessarily be a man-rem reduction based on the population distribution encountered.

K. Swimming Doses

As with the lake doses, the swimming doses are only discussed for Alcove Reservoir but apply to all lakes in the area of interest. For a person who happens to swim in the contaminated lake, for periods shortly after the deposition, the total dose is .47 rem/hr and will diminish as the nuclides decay. Although the percentage contribution of the nuclides is not the same in general the same nuclides contribute to the total dose as to the water ingestion dose. Actually, it should be noted that swimming and boating are not permitted in Alcove Reservoir.

L. Evacuation Model

Using the evacuation parameters of evacuation rate $\lambda = 8.30$ days^{-1} ($T_{1/2}$ = two hours), the fraction not evacuated A = .10, the time between the awareness of core meltage and actual leakage T = .02 days (½ hour), the time needed to interpret the data and issue the warning TL = .02 days, and the average wind speeds, the population remaining after passage

of the cloud range from 96-99% in the nearest radius to from 19-35% in the outermost sector when evacuation is carried out to a full 50 miles downwind from the accident site. It is interesting to note that the direction of highest dose per individual, west, is one of the directions allowing the greatest time for evacuation since the submersion and inhalation doses at each location depend on the stay time of the cloud. The westerly direction allows from 4% to 88% of the population (according to their distance from the accident site) to evacuate while the direction of smallest dose per individual south-southeast allows 1% at ½ mile to 65% at 50 miles. In the Troy-Albany area, approximately 60% of the people could be evacuated under average conditions. The sector of highest man-rem dosage south-southwest allows 2-73% evacuation.

With the above evacuation, man-rem dosage can be significantly reduced. To the north, the reduction in man-rem dosage is found to be 56%; to the south-southeast, a 33% reduction; to the south-southwest, 40%; and to the west, 39%; and the overall reduction in dose is found to be approximately 40%.

Evacuation to 10 miles in each accident case reduces the man-rem dosage only approximately 8%. Because of the average cloud speeds, evacuation to 10 miles would not remove enough people to satisfactorily reduce the total dosage. The highest winds recorded in the area were 71 miles per hour from the northwest. Using this representative wind speed, the individual doses are reduced 4 to 6 times as are the amounts of deposition. When rainfall is considered to occur during the accident period, no significant variations are seen in the dose to an individual. Since more of the nuclides are

washed out, the ground deposition dose reaches two to three times its reference value with dry weather, but this is still only a small percentage of the total dose received.

If the evacuation rate is taken as 4.15 days^{-1} corresponding to an evacuation "half-life" of four hours, or one-half the reference rate, evacuation in the path of westerly winds allows only 2% to escape at ½ mile while 78% can evacuate from 50 miles away (10% less than with a two hour evacuation "half-life"). To the south-southeast, from 1% to 49% can evacuate and in the Troy-Albany area, approximately one-half would be able to leave in time, resulting in a 45% reduction in dose (compared with a 68% reduction with the quicker evacuation rate). Overall, there is only a 25% reduction in man-rem dosage due to evacuation. With a four hour evacuation "half-life" plus a one hour delay to evaluate the data and issue the warning, there will be no evacuation within two miles and very little out to five miles. In Albany, the population could be reduced by 41% (or about 10% less than before) which results in a 31% reduction in dose. Overall there is a 20% reduction in dose in this evacuation case. These results are summarized in Figure 13.

Figure 13

EFFECTS OF EVACUATION PARAMETERS

Maximum Evacuation Distance (miles)	$T_{1/2}$ (hours)	TL (hours)	T (days)	Relative Dose at Albany	Overall Relative Dose (man-rem)
	no evacuation			100%	
50	2	½	.02	32%	60%
10	2	½	.02	100%	92%
50	4	½	.02	55%	75%
50	4	1	.02	69%	80%

PART VI

DISCUSSION AND CONCLUSIONS

It seems obvious that a reactor accident will require a number of experts to outline contaminated areas and insure area and water monitoring. The greater the severity of the release, the more experts will become involved. With northerly winds, the water in Alcove Reservoir will become contaminated requiring alternate water supplies. The values listed in Table 27 do not allow for decay in transmission but are high enough that contamination will remain for some time without special treatment.

Nuclide Concentration In Milk

Estimation of radionuclide concentrations in milk is a difficult task, and data taken from environmental samples is not easily represented by a single curve even for each isotope as evidenced by results in the literature (1, 7, 14, 15, 23). As a result, the concentrations of the various nuclides although reasonable figures, are by no means exact. They do show, however, that the concentrations will be extremely high so that if the cows do live to produce milk, it will be contaminated for months after the event, with high concentrations of the long-lived isotopes of ^{90}Sr and ^{137}Cs.

It can be seen that several protective actions can be used to reduce dose even in this worst case. Replacing forage crops with uncontaminated feed is extremely important in reducing concentrations and doses. For example, the tenth life of ^{137}Cs can be reduced from 67 days to 8 days by placing a cow on uncontaminated feed. As stated, removal of the milk must be accomplished initially and extensive

monitoring over a wide area will be in order. Taking protective actions includes the weighing of risks of taking no action against the implications of the action, but in this case, there will be no reason for hesitant action by this point in time. Assumptions following contamination are that:

1. The contaminating event is a single acute occurrence within a few hours.

2. Previous accumulation of nuclides is negligible.

3. The forage crop is grass which supplies all of the roughage consumed, and it is growing at its normal rate.[22]

Total Dose Received

Summation of the whole body doses due to a single radioactive cloud submersion, a one day's dose due to ground contamination, and a 30-day integrated dose due to inhalation of various radionuclides during the cloud passage yield representative totals useful in comparing the relative doses. The highest dose per individual occurs in the western sector with 4846 rem at one-half mile to 3.66 rem at 47½ miles and 1604 rem to 2.85 rem to the north. Specific values for three directions are shown in Figure 14. The relative contributions of the three sources of whole body dose vary with distance as shown in Figure 15 with the inhalation contribution running from approximately 60% at one-half mile to over 77% at 47½ miles while the cloud submersion dose decreases in the same interval from 36 to 20%. A possible explanation for this effect is that the cloud being carried downwind diffuses vertically and horizontally with the resultant vertical midpoint of the cloud mass z rising with distance. In the MODAIREM Code, equal cloud deposition from all parts of the cloud is assumed. The receptor lies

Figure 14

TOTAL DOSE (REM)

Distance (mi)	North	West	SSW
.5	1604	4846	2092
1.5	593	1622	780
2.5	293	768	382
3.5	178	317	231
4.5	122	293	157
7.5	57	129	72
15	19.2	38	22.9
22.5	9.88	17	11.2
27.5	7.06	11.5	8.11
35	4.82	7.40	5.31
42.5	3.44	4.87	3.87
47.5	2.85	3.66	3.04

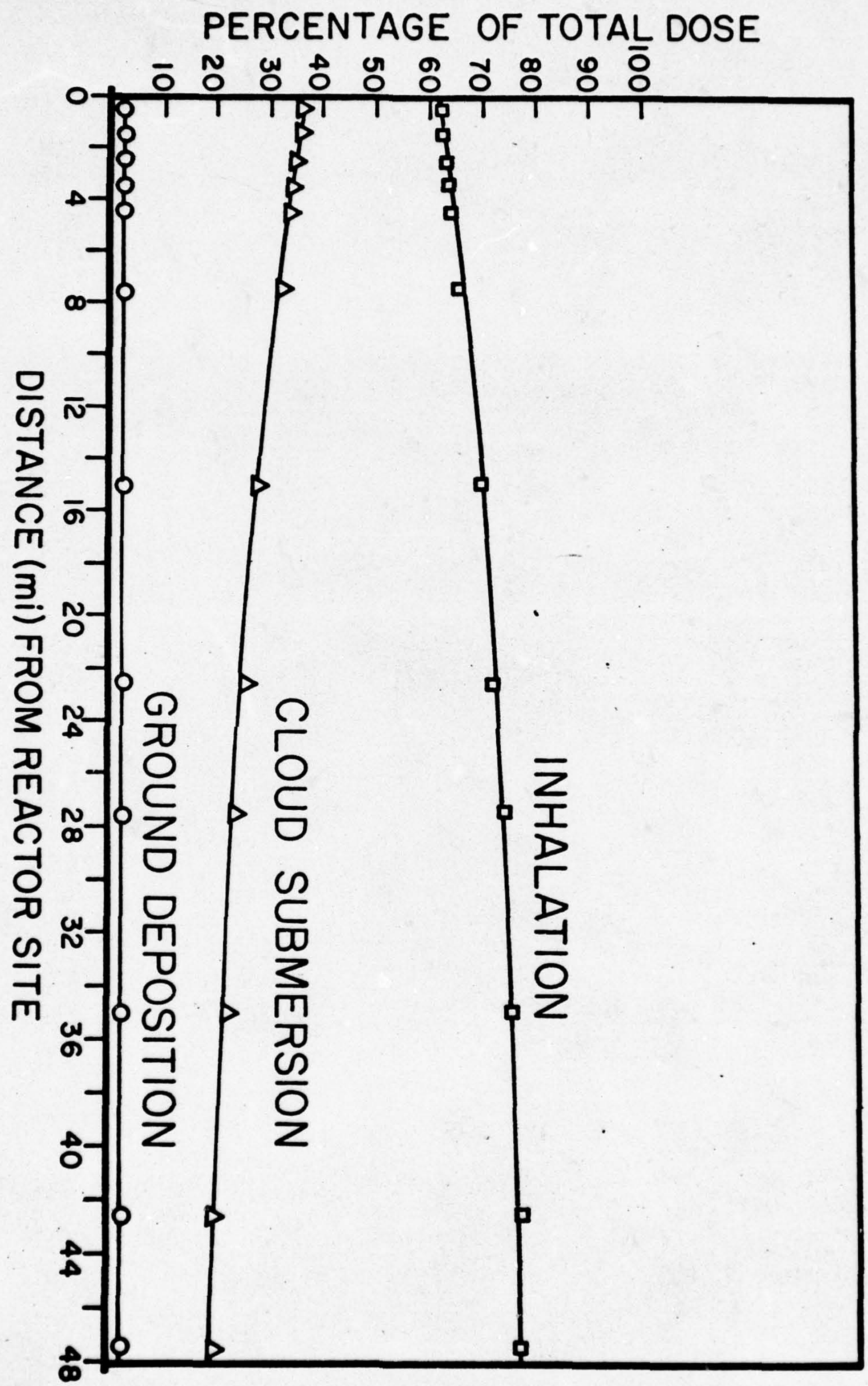


FIGURE 15 RELATIVE DOSES vs DISTANCE FROM ACCIDENT SITE (SSW)

Figure 16

RELATIVE NUCLIDE CONCENTRATIONS TO TOTAL DOSE

Isotope	Contribution to Total Dose (%)
^{131}I	18.9
^{133}I	11
^{132}Te	10.5
^{135}I	8.4
^{140}Ba	7.0
^{132}I	5.3
^{99}Mo	4.9
^{103}Ru	4.4
^{134}I	2.5
^{106}Ru	.3
^{137}Cs	.3
^{134}Cs	.3

in the center of this semi-infinite uniform medium and the cloud radiation dose at any distance can be found using reciprocity relationships, and it is essentially a three dimensional effect which depends directly on the passage of the cloud. The inhalation dose is essentially a point effect depending on the concentration of the cloud at that location during passage. That is, close to the accident site where the cloud is small, it passes over the receptor, and most of the cloud contributes to the submersion (radiation) dose and likewise for the inhalation dose. Far from the accident, part of the cloud which has expanded does not contribute proportionally as much as close to the receptor since the potential target (receptor) relative area is smaller. The inhalation dose, however, although smaller due to expansion, and assuming homogeneity, all contributes to the total dose. Continuing this assumption, and averaging the relative doses yields the average contributions to the total dose which are 69.7% due to inhalation, 28% due to cloud radiation and 2% due to cloud deposition. With these figures, the relative contributions of each isotope to the total dose can be calculated, and are shown in Figure 16.

Evacuation vs. Dose

One can see from Figure 14 that doses to the individual drop sharply as the distance from the site increases. An acute exposure received of less than 150R will result in no lethalities.[2] It has been seen already that evacuation of 10 miles reduced the man-rem only slightly, however, its effect on the individual's dose is very important in developing an emergency plan. Evacuation to over 7½ miles from the site reduces the dose equivalent to under 130 rem in the worst

case. In fact, in the most probable wind direction, north, the total is reduced to 57 rem. The manner of addition of doses described previously is again emphasized. Evacuation to about 7½ miles would effect the towns of Catskill, Saugerties and Tivoli.

A word must be said concerning any proposed evacuation. In a study done[28] it was found that successful evacuation can be accomplished given sufficient warning and adequate reaction time according to an inverse relationship between the population density and the evacuation time. The 1990 population of the area near Cementon shows a population density of between approximately 200-600 people per square mile which corresponds to four to six hours evacuation time necessary.[28] This agrees with the evacuation half-time of two hours used in the model. This appears to be an accurate representation and is extended by the model which shows that the radioactive cloud takes approximately one hour to travel to 7½ miles which results in few individuals being able to leave the area in time. Then the time to evacuate from a distance closer to the site is even less and successful evacuation is less probable. It has been shown that evacuation is sensitive to the time necessary for evaluation of the accident and issuance of a warning. Due to the encompassing consequences of taking such action, the person responsible would make sure he was making a correct decision, and if the decision is ultimately positive, every minute in decision enlarges the consequences.

Evacuation vs. Shelter

A special aspect of evacuation during a nuclear event is first, who should evacuate and second, where should they go? In answering

these questions, one must ask first, in what direction are the winds which are carrying the radioactivity travelling, and second, in what direction will they blow in the future. Given evacuation routes, even if known, may cause many travellers to move into the path of the cloud which would be otherwise avoided if the wind should suddenly shift direction. Most evacuation can be carried out in an orderly fashion without panic, according to an EPA study[28] but there is potential for trouble due to the psychological response to an event of this type and the very short times required to leave the area.

The worst case results if a person does not leave the area since he would receive the maximum dose. The best situation is an evacuation away from the cloud resulting in no dose. The majority of the population, as it has been shown, will fall somewhere in between. An unsuccessful attempt at evacuation will result in a needlessly high dose although the farther away from the site, the better the chances for evacuation. Remaining in place and taking shelter is an alternative that should be considered. For example, in Cementon there are locations designated as fallout shelters which provide room for 2,224 individuals with a protection factor of at least 40 for gamma radiation.[30] If in addition, two dry bath towels or similar material are used as a makeshift filter in the absence of civilian protective masks, it has been estimated that 85% of the inhalation dose can be avoided. Since inhalation dose primarily occurs during cloud passage, the estimated dose can further be reduced. It takes approximately two hours to exchange air volume in a building, therefore, a dilution can take place. The better sealed a building is, the less the inhalation dose. Of course absolute filters, especially charcoal activated filters drastically

reduce the total dose through a reduction in the thyroid dose. If the effect on inhalation dose is to lower it by an additional 25%, then even at one mile no protected person will receive over 150 rem. Clearly, this is not entirely satisfactory, but this is a highly unlikely event and is superior to an attempt at evacuation for short distances from the reactor where the cloud's travel time to one mile is approximately ten minutes. Remaining in place resulting in a dose from the nuclides deposited on the ground does not appreciably add to the dose. The use of immediately available shelters and either stockpiled protective masks or makeshift filters is reasonably effective. In rural areas, basements could be used with similar success. As a public relations gesture as well as a protective one, the construction of the plant with a large hall equipped with a filtration system at an easily accessible location in or near Cementon which could provide a type of civic center and recreational hall. This scheme has two additional benefits. First, it takes advantage of the inertia of the population who tend to continue to take actions they have in the past rather than to undertake new patterns. That is, a movement into the cement plants, into a basement or into a recreational hall is more likely to occur than an evacuation of families, even if time were available. Second, the sheltering of individuals would allow various disaster mechanisms and health physics personnel to arrive, assess the situation and proceed on the best course of action with a minimum of confusion. The warning of individuals of the need for moving into shelters would be no more difficult than warning them of the need to evacuate, in fact, it could be much easier. If the local population is educated to the facts and dangers involved and simple protective actions to take, one day in a shelter could be

tolerable. A type of siren or system of sirens which could be heard for at least 10 miles could be used as a warning device for everyone in the area but would require that the population know what it meant. It is unfortunate, however, that this type of action, clearly the quickest and therefore the best would not be used because of the accentuation of alarmist tendencies by the opponents of nuclear power. Again they would question the need for these actions if nuclear power were so safe, so in preparing for an extremely unlikely event, fears are raised that an accident will take place because of preparation for all eventualities.

Comparison With WASH-1400

Using values for lethal doses of a five day LD_{50} to the gastrointestinal tract of 4,000-6,000 rad, an estimated LD_{50} of 3,000 rad to the lung, and whole body LD_5 of 225R, LD_{50} of 400R, and LD_{90} of 5-600R, the worst case to the west yields and estimated 326 acute deaths and the most probable case to the north where the wind blows one quarter of the time, an estimated 12 acute deaths from this accident assuming no protective actions whatever. The wind blows to the west less than 2% of the time. The number of thyroid modules is extremely high since there are over 3,000 rem per person to the thyroid out to 25 miles to the west, and out to 15 miles to the north. There appears from Table 12 that nodules will be formed in children for downrange throughout the range of study if no protective actions are taken. Since the majority of the thyroid dose comes from inhalation, this is another reason to reduce the inhalation dose. Comparison of these results with Appendix VI of WASH-1400 show:

Highest man-rem in this study (SSW)	=	2.79×10^6
Average man-rem, WASH 1400	=	2.8×10^6
Peak acute fatalities, this study	=	326
Peak acute fatalities, WASH 1400	=	1,100
Fatalities (northerly winds)	=	12
Average acute fatalities, WASH 1400	=	34

Both studies are to an extent averages over populations, areas and meteorological conditions.

Thus, the consequences of a very serious reactor accident have been shown. Rather than concentrate on one single area, a broad perspective was taken, and it is expected that several of these areas for the Cementon plant will be expanded upon and refined in the future. Once again, the probability of this accident must be emphasized as being very small.

If the population close to the plant were educated in basic protective action and an emergency plan, there is a possibility of preventing acute fatalities. There would, however, be many long-term effects that this study has not considered. Putting the benefits of the plant in perspective with the risks involved, this study must support the location at Cementon as being adequate in this respect. It is qualitatively safer than the case studied in WASH 1400, and the worst effects can be considerably mitigated.

Table 1

DOSE INHALATION FACTORS (mrem/sec/Ci/m^3)

(Rem/Ci)(Breathing rate of 2.2×10^{-4} m^3/sec)(1000 mrem/rem)

Isotope	WB (30 day)	Lung (30 day)	Thyroid (50 yr)	GI tract (50 yr)
KR 85	0	0	0	0
KR 85*	0	0	0	0
KR 87	0	0	0	0
KR 88	0	0	0	0
SR 89	858	17160	0	9900
SR 90	352	41360	0	7920
SR 91	77	1210	0	5280
Y 90	132	4620	0	15620
Y 91	572	18920	0	9460
Zr 95	1078	16940	0	4840
Zr 97	86	2200	0	15620
Nb 95	440	7480	0	2420
Mo 99	145	2640	0	6600
Tc- 99*	2	17.8	0	99
Ru 103	170	8140	0	4840
Ru 105	14	352	0	2420
Ru 106	627	51480	0	23540
Rh 105	22	572	0	2420
Te 129	4	75	8.8	462
Te 129*	968	23540	1474	12100
Te 131*	161	2420	220	7920
Te 132	431	6820	550	12100
I 131	528	4620	323400	242
OI 131	528	4620	323400	242
I 132	29	198	11660	528
I 133	125	1122	87120	484
I 134	9	79	5500	484
I-135	64	440	27060	462
OI-135	64	440	27060	462
Xe 133	0	0	0	0
Xe 135	0	0	0	0
Cs 134	3300	11000	0	462
Cs 136	1210	3300	0	242
Cs 137	1804	7700	0	242
Ba 140	1584	26840	0	12100
La 140	184	3740	0	12100
Ce 141	178	5060	0	2420
Ce 143	74	2200	0	6600
Ce 144	1452	47520	0	24200
Pr-143	249	6380	0	5280
Nd-147	255	5280	0	4840
Pm 147	79	2640	0	1210
Pu 238	66880	2200000	0	9460
Pu 239	62260	2112000	0	9460

Table 2

WIND FREQUENCIES BY STABILITY CLASS FOR WINDS BLOWING TO 1 SECTOR (hourly observations/%)[13]

	A	B	C
N	89/4.93	81/4.49	73/4.04
NNE	31/3.73	15/.81	36/4.33
NE	3/1.31	4/.69	7/3.06
ENE	1/.81	1/4.19	1/.81
E	1/.69	1/4.45	3/2.07
ESE	4/1.29	13/	14/4.52
SE	13/2.75	21/4.42	26/5.51
SSE	23/3.63	28/	33/5.21
S	44/5.14	23/2.69	32/3.74
SSW	26/2.69	23/2.38	36/2.73
SW	50/11.71	29/6.79	29/6.79
WSW	10/6.33	14/8.86	16/10.13
W	5/5.0	3/3.0	8/8.0
WNW	6/7.14	5/5.95	9/10.71
NW	8/6.56	5/4.1	9/7.38
NNW	20/5.08	18/4.57	23/5.84

Table 2 continued

	D	E	F
N	613/33.96	851/47.15	88/4.88
NNE	240/28.88	396/47.65	100/12.03
NE	62/27.07	111/48.47	28/12.23
ENE	34/27.42	55/44.35	24/19.35
E	67/46.21	48/33.1	20/13.79
ESE	151/48.71	102/32.9	19/6.13
SE	188/39.83	175/37.08	47/9.96
SSE	231/37.44	269/42.43	43/6.78
S	336/39.25	372/43.46	46/5.37
SSW	448/46.42	383/39.69	45/4.66
SW	158/37.0	146/34.19	14/3.28
WSW	56/35.44	55/34.81	7/4.43
W	39/39.0	39/39.0	6/6.0
WNW	28/33.33	32/38.1	4/4.76
NW	45/36.89	40/32.79	13/10.66
NNW	123/31.22	182/46.19	26/6.6

Table 3

WIND SPEEDS BY STABILITY CLASS (mph/ $\frac{m}{sec}$)[13]

	A	B	C
N	12.71/5.68	12.24/5.47	12.61/5.64
NNE	11.37/5.08	11.8/5.28	10.81/4.83
NE	7.5/3.35	12.88/5.76	9.43/4.22
ENE	5.5/2.46	15/6.71	15.0/6.71
E	5.5/2.46	15/6.71	11.83/5.29
ESE	15/6.7	12.58/5.62	13.21/5.91
SE	16.42/6.71	14.24/6.37	12.56/5.61
SSE	18.09/8.09	15.66/7.0	14.17/6.33
S	17.97/8.03	14.26/6.37	14.44/6.46
SSW	12.46/5.57	13.11/5.86	11.25/5.03
SW	10.23/4.57	10.4/4.65	8.64/3.86
WSW	6.05/2.7	5.07/2.27	5.41/2.42
W	6.6/2.95	2/.89	5.06/2.26
WNW	4.33/1.94	2/.89	4.33/1.94
NW	4.19/1.87	5/2.24	2.78/1.24
NNW	5.75/2.57	6.42/2.87	4.59/2.05

Table 3 continued

	D	E	F
N	12.87/5.75	11.26/5.03	10.95/4.9
NNE	10.22/4.57	9.53/4.26	9.14/4.09
NE	9.4/4.2	6.77/3.03	6.41/2.87
ENE	7.82/3.5	6.02/2.69	5.67/6.12
E	9.4/4.2	6.01/2.69	4.78/5.23
ESE	12.03/5.38	8.8/3.93	6.21/2.78
SE	11.3/5.05	9.81/4.39	6.71/3.0
SSE	14.37/6.42	11.95/5.34	6.84/3.06
S	12.74/5.7	9.76/4.36	5.89/2.63
SSW	11.5/5.14	8.0/3.58	5.3/2.37
SW	7.53/3.37	5.55/2.48	4.64/2.07
WSW	5.39/2.41	4.13/1.85	3.0/1.34
W	4.21/1.88	3.87/1.73	3.17/1.42
WNW	4.41/1.97	3.86/1.73	3.75/1.68
NW	5.08/2.27	3.8/1.7	6.27/2.8
NNW	7.29/3.26	6.69/2.99	7.42/3.32

Table 4

YEAR 1990 EXPECTED POPULATION[13]

Radius (mi)	N/S	NNE/SSN	NE/SW
(0-1)	3	0	0
	0	3	100
(1-2)	3	0	17
	13	175	272
(2-3)	23	44	55
	32	215	122
(3-4)	48	52	139
	73	543	348
(4-5)	180	1039	107
	104	505	204
(5-10)	1337	5109	10,915
	872	2580	4446
(10-20)	3877	7869	10,639
	19,868	58,206	8790
(20-25)	6007	11,400	6006
	14,000	14,951	3765
(25-30)	6007	11,400	6006
	14,000	14,951	3765
(30-40)	114,379	133,932	11,436
	182,797	18,037	17,213
(40-45)	103,014	86,034	5719
	86,843	38,066	9389
(45-50)	103,014	86,034	5719
	86,843	38,066	9389

Table 4 continued

Radius (mi)	ENE/WSW	E/W	ESE/WNW	SE/NW	WWE/NNW
(0-1)	0	3	3	0	0
	41	11	3	0	3
(1-2)	193	127	213	308	245
	0	11	29	0	8
(2-3)	143	73	155	143	167
	237	111	15	92	82
(3-4)	130	110	123	92	178
	153	66	90	59	82
(4-5)	130	167	76	110	216
	579	343	211	262	85
(5-10)	1320	923	765	1168	595
	15,094	2758	2213	1257	1266
(10-20)	6395	2769	1936	3720	6499
	6998	989	1794	2550	3796
(10-15)	1791	4900	2758	8067	6500
	1565	1117	920	1167	1715
(25-30)	1791	4900	2758	8067	6500
	1565	1117	920	1167	1715
(30-40)	47,218	5085	9232	10,032	28,398
	1737	4008	3371	2628	6491
(40-45)	17,973	1957	28,816	12,517	24,012
	5759	1271	2897	6298	6178
(45-50)	17,973	1957	28,816	12,517	24,012
	5759	1271	2897	6298	6178

Table 5

MESH POINT DISTANCES IN METERS[13]

Radius	Midpoint	Lower Radius	Upper Radius
1	805	0	1609
2	2414	1609	3219
3	4023	3219	4828
4	5633	4828	6437
5	7242	6437	8047
6	12,070	8047	16,093
7	24,140	16,093	32,187
8	36,210	32,187	40,234
9	44,257	40,234	48,280
10	56,327	48,280	64,374
11	68,397	64,374	72,420
12	76,444	72,420	80,467

Table 6

NUCLIDE SOURCE DATA[2]
For 1200 MW(e) After 550 Days of Full Power Operation

Isotope	Half-Life(d)	Decay Constant(sec^{-1})
KR85	3.9E03	3.9E-03
KR85*	1.8E-01	4.46E-05
KR87	5.3E-02	1.51E-04
KR88	1.16E-01	6.91E-05
Sr89	5.06E01	1.59E-07
Sr90	1.05E04	7.64E-10
Sr91	4.0E-01	2.01E-05
Y90	2.7E00	2.97E-06
Y91	5.9E01	1.36E-07
Zr95	6.55E01	1.22E-07
Zr97	7.0E-01	1.15E-05
Nb95	3.5E01	2.29E-07
Mo99	2.8E00	2.86E-06
Tc99*	2.5E-01	3.21E-05
Ru103	4.0E01	2.01E-07
Ru105	1.8E-01	4.46E-05
Ru106	3.68E02	2.18E-08
Rh105	1.5E00	5.35E-06
Te129	4.8E-02	1.67E-04
Te129*	3.41E01	2.35E-07
Te131*	1.25E00	6.42E-06
Te132	3.25	2.47E-06
I131	8.05E00	9.96E-07
MI131	8.05E00	9.96E-07
I132	1.0E-01	8.02E-05
I133	8.75-01	9.17E-06
I134	3.6E-02	2.23E-04
I135	2.8E-01	2.87E-05
MI135	2.8E-01	2.86E-05
XE133	5.3E00	1.51E-06
XE135	3.8E-01	2.11E-05
CS134	7.52E02	1.08E-08
CS136	1.29E01	6.22E07
CS137	1.1E04	7.29E-10
BA140	1.28E01	6.27E-07
LA140	1.66E00	4.83E-06
CE141	3.28E01	2.45E-07
CE143	1.37E00	4.86E-06
CE144	2.85E02	2.81E-08
PR143	1.36E01	5.89E-07
ND147	1.1E01	7.29E-07
PM147	9.6E02	8.36E-09
PM149	2.2E00	3.65E-06
PU238	3.2E04	2.51E-10
PU239	8.7E06	9.22E-13

Table 6 continued

Isotope	Source(Ci)	Fraction Released	Total Release(Ci)
KR85	7.2E05	.8	5.76E05
KR85*	3.12E07	.8	2.50E07
KR87	6.24E07	.8	4.99E07
KR88	9.12E07	.8	7.30E07
Sr89	1.32E08	.05	6.60E06
Sr90	6.24E06	.05	3.12E05
Sr91	1.56E08	.05	7.80E06
Y90	6.24E06	.003	5.04E05
Y91	1.68E08	.003	5.04E05
Zr95	1.92E08	.003	5.76E05
Zr97	1.92E08	.003	5.76E05
Nb95	1.92E08	.003	5.76E05
Mo99	1.92E08	.4	7.68E07
Tc99*	1.68E08	.4	6.72E07
Ru103	1.2E08	.4	4.80E07
Ru105	6.96E07	.4	2.78E07
Ru106	2.28E07	.4	9.12E06
Rh105	6.96E07	.4	2.78E07
Te129	3.36E07	.4	1.34E07
Te129*	1.2E07	.4	4.80E06
Te131*	1.8E07	.4	7.20E06
Te132	1.44E08	.4	5.76E07
I131	1.02E08	.6	6.12E07
MI131	1.02E08	.006	6.12E05
I132	1.44E08	.6	8.64E07
I133	2.04E08	.6	1.22E08
I134	2.4E08	.6	1.44E08
I135	1.8E08	.6	1.08E08
MI135	1.8E08	.006	1.08E08
XE133	2.04E08	.8	1.63E08
XE135	3.12E06	.8	2.50E07
CS134	2.04E06	.4	8.16E05
CS136	7.2E06	.4	2.88E06
CS137	6.96E06	.4	2.78E06
BA140	1.92E08	.05	9.60E06
LA140	1.92E08	.003	5.76E05
CE141	1.92E08	.003	5.76E05
CE143	1.8E08	.003	5.40E05
CE144	1.32E08	.003	3.96E05
PR143	1.8E08	.003	5.40E05
ND147	7.2E07	.003	2.16E05
PM147	2.04E07	.003	6.12E04
PM149	4.8E07	.003	1.44E05
PU238	1.2E05	.003	3.60E02
PU239	1.2E04	.003	3.60E01

Table 7

NEW DEFINITIONS INTRODUCED IN MAIN PROGRAM

ACTDEN	Ground deposition in pCi/m^2
AP	In the evacuation mode, the fraction of the population not evacuated.
DOSFAC	Dose factors ($Rem/hr/Ci/m^2$).
DR	Dose rate rem/hr.
M	Number of radii--must be an even number
NEVAC	Evacuation mode 0 = No evacuation -1 = Evacuation outside farthest sector 1 = Evacuation outside radius m/2 (away from the cloud's direction)
NORGAN	Organ of interest for ground deposition dose 0 = WB, 1 = Skin.
TAWL	Time between awareness of impending core melt and leakage in days.
TD	Total integrated dose due to ground deposition mrem.
TIME	Integrated time(days) spent standing on contaminated ground.
TLAG	Time lag associated with interpretation of data and issuance of warning to evacuate.
TOTPOP	Total population being considered.
XLAM	Measure of evacuation rate (days).
XLAMBD	Decay factor per nuclide ($days^{-1}$).
XMANRM	Total man rem due to 1 nuclide.
POPUL	Population in each mesh point modified by evacuation.
FX	Population fraction remaining at the time of cloud arrival.
FX2	Population fraction remaining after TIME days of evacuation.
POP2	Population remaining after TIME days of evacuation.

Table 8

DEFINITIONS - SUBROUTINE RIVCON

AAVCRS	Average cross sectional area of the river in a reach concentration (pCi/sec) in water due to the nuclide in the previous reach.
CCI	Concentration due to the contribution of direct deposition and the plant discharge (pCi/l)
CONCEN	Concentration in reach before water treatment ($\frac{pCi}{l}$).
CROSS	River cross sectional area
FINAL	Concentration (pCi/l) of isotope LL in each reach for treated water.
FRACT	Fraction of dissolved nuclide passing through water treatment facilities class 3 or 4 (If unknown, set = 1.).
IIRECH	Number of reaches
IREACH	Counter for IIRECH
NINOUT	Tide direction = 0 if tide is going out at beginning of accident. Tide direction = 1 if tide is going in at beginning of accident.
NDEP	Counter for NDEPTH
NDEPTH	Number of depths/profile (3, 5, 7, 9 or 11).
NNPROF	Counter for NPROF
NPROF	Number of profiles/reach (20 maximum).
NUMB, MM,II	Reach number and mesh point location of the reach. Numb should start at 1 end of the river and each reach met numbered consecutively whenever a new mesh point is reached.
OUTVEL	Velocity (mi/hr) of water with the tide going out.
PLTDEN	pCi/sec added to the water due to plant discharge for each nuclide.
QQAVE	Average flow rate (l/sec) in each reach.
SOLUB	Solubility factor for each nuclide.
SURFA	Surface area of river in the reach (ft^2).

Table 8 continued

TIMIN	Time (hr) the tide flows in.
TIMOUT	Time (hr) the tide flows out.
TOTFIN	Total concentration of nuclides (pCi/l) in processed water in reach.
TVLTIM	Time for a packet of water (avg) to traverse the length of the reach.
TWIDTH	River width.
WATFAC	Water treatment facility in the reach: 0 = no plant, 1 = class 1 plant, 2 = class 2 plant, 3 = class 3 plant, 4 = class 4 plant.
XLRCH	Length of reach (miles).
XDEPTH	River depth
XINVEL	Velocity (mi/hr) of water with the tide going in
XXTIM	Time delay desired before computing water concentrations only 1 XXTIM/run allowed, must be in whole days, 0 = RIVDOS calculations not desired.
RADIUS	MM location of reach.
SECTOR	II location of reach.
CCONC	Total concentration (pCi/l) in a reach for nuclide LL.

Table 9

DEFINITIONS - SUBROUTINE FISHR

CF(11)	Concentration factor for fresh water fish (pCi/kg/pCi/l).
FISHCN (IREACH,LL)	Concentration (pCi/kg) of nuclide LL in reach IREACH in fish.
FISHT (IREACH)	Total concentration (pCi/kg) in reach IREACH in fish.

DATA REQUIRED - SUBROUTINE FISHR

	Column	Title	Format
L Cards	1-10	Concentration Factor for fresh water fish	F10.0

Table 10

DEFINITIONS - SUBROUTINE LAKEDS

BOAT	Time spent boating on the contaminated lake (hrs).
BOATDF	Whole body dose factors for boating on the contaminated lake (mrem/hr/pCi/l).
BOATSK	Skin dose factor for boating on the contaminated lake
DESDOS	Dose desired: 0= whole body, 1 = skin, 2 = both whole body and skin.
DELAY	Time (days) after lake contamination the dose is desired.
DOSBSK	Skin dose due to boating on the contaminated lake.
DOSBWB	Whole body dose due to boating.
DOSSSK	Skin dose due to swimming in a contaminated lake.
DOSSWB	Whole body dose due to swimming.
FINAL	Concentration (pCi/l) of treated water.
SETUP	Indicator - I =run subprogram I times for I lakes, 0 or blank card = subprogram not required.
SKINDF	Skin dose factor for swimming in a contaminated lake.
SUM	Total concentration (pCi/l) of nuclides for treated water.
SURF	Lake surface area (ft^2).
SWIM	Time spent swimming in the contaminated lake (hrs).
SWIMDF	Whole body dose factors for swimming in the contaminated lake.
TOTDOS	Total concentration (pCi/l) of nuclides for untreated water.
VOLUME	Lake volume in gallons.
CON	Lake concentration (pCi/l) of nuclide LL.

Table 11

DEFINITIONS - SUBROUTINE MILK

BIO	Biological half life in forage crop (days).
BF	Forage crop concentration factor (pCi/kg per pCi/kgsoil).
CD	Milk concentration (pCi/l).
CBIO	Biological half life in the cow.
DAY	Time (days) after accident release.
DRINK	Drinking water type - trough, river, lake 0 = trough (underground water), 1 = river, 2 = lake.
INC	Increments (days) desired in dose calculations.
LAMEFF	Effective decay constant = $\lambda_{\text{radiological}} + \frac{.693}{T_{1/2}\ \text{Biological} = 14\ \text{days}}$.
LEAVE	Dairy cow evacuation mode after exposure. (0 = no evacuation, 1 = evacuation after 1 day).
XLD	Ingestion of drinking water by the dairy cow (L/day).
NUMBER	Number of mesh points not serviced by underground water supply. If = -1, go to return.
P	Constant: 224kg soil/m^2plowlayer.
QF	Fresh forage ingestion by dairy cow (kg/day).
R	Deposition retention factor.
SD	Coefficient of transfer from diet to milk (pCi/l per pCi/day).
TAREA	Typical trough area (ft^2).
TOTAL	Total milk concentration in each mesh point (pCi/l).
TOTDAY	Maximum number of post accident days to calculate doses.
VOL	Typical trough capacity (gal).
W	Concentration (pCi/l) in drinking water.
YF	Forage crop yield (kg/m^2).

Table 12

REM/PERSON TO THE THYROID FOR SELECTED DIRECTIONS

Average Radius (mi)	SSW	W	SSE	N
.5	3.0E05	7.1E05	---	2.3E05
1.5	1.1E05	2.5E05	8.4E04	8.7E04
2.5	5.7E04	9.5	4.3E04	4.3E04
3.5	3.5E04	7.2E04	2.7E04	2.7E04
4.5	2.4E04	4.9E04	1.9E04	1.9E04
7.5	1.1E04	2.3E04	8800	8900
15	4100	7600	3200	3200
22.5	2100	4200	1700	1700
27.5	1600	2600	1300	1300
35	1100	1800	900	900
42.5	790	1200	660	670
47.5	660	1000	560	570

AD-A052 681 RENSSELAER POLYTECHNIC INST TROY N Y F/G 6/18
RADIATION DOSE ANALYSIS OF A PWR 1 ACCIDENT FOR THE PROJECTED R--ETC(U)
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Table 13

THYROID MAN-REM

		Major Contributing Nuclides
N	2.71E08	I131 = 60%
NNE	4.27E08	I133 = 30%
NE	3.01E08	I135 = 7%
ENE	2.02E08	
E	8.72E07	
ESE	9.10E07	
SE	1.26E08	
SSE	1.28E08	
S	4.50E08	
SSW	4.98E08	
SW	2.59E08	
WSW	4.36E08	
W	1.33E08	
WNW	1.33E08	
NW	9.86E07	
NNW	9.80E07	

Table 14

REM/PERSON TO THE GI TRACT FOR SELECTED DIRECTIONS

Average Radius (mi)	SSW	W	SSE	N
.5	2.06E04	4.86E04	1.46E04	1.59E04
1.5	7700	1.64E04	5700	5880
2.5	3810	7700	2880	2910
3.5	2310	4500	1770	1780
4.5	1470	2980	1220	1220
7.5	730	1340	579	576
15	245	400	201	201
22.5	120	160	101	103
27.5	84	110	72	75
35	56	71	50	52
42.5	39	45	35	37
47.5	32	36	29	31

Major Contributing Nuclides

TE132	30%
MO 99	22%
RU103	10%
RU106	9%
BA140	5%

Table 15

GI TRACT MAN-REM

N	1.55E07
NNE	2.40E07
NE	1.79E07
ENE	1.15E07
E	5.27E06
ESE	5.44E06
SE	7.58E06
SSE	7.66E06
S	2.46E07
SSW	2.90E07
SW	1.55E07
WSW	2.56E07
W	7.72E06
WNW	7.72E06
NW	5.32E06
NNW	5.35E06

Table 16

REM/PERSON TO THE LUNGS FOR SELECTED DIRECTIONS

Average Radius (mi)	SSW	W	SSE	N
.5	2.22E04	2.52E04	1.57E04	1.71E04
1.5	8360	1.78E04	6150	6340
2.5	4140	8480	3120	3150
3.5	2520	5000	1920	1930
4.5	1724	3340	1330	1330
7.5	812	1530	637	633
15	278	474	225	225
22.5	137	203	115	118
27.5	98	139	84	86
35	67	91	58	60
42.5	47	59	42	43
47.5	39	47	34	36

Table 17

LUNG INHALATION MAN-REM

N	1.82E07
NNE	2.87E07
NE	2.02E07
ENE	1.35E07
E	5.92E06
ESE	6.56E06
SE	8.63E06
SSE	8.92E06
S	2.84E07
SSW	3.21E07
SW	1.75E07
WSW	2.88E07
W	8.78E06
WNW	7.54E06
NW	1.09E07
NNW	5.28E06

Table 18

WHOLE BODY REM/PERSON DUE TO CLOUD SUBMERSION FOR SELECTED DIRECTIONS

Average Radius(mi)	SSW	W	SSE	N
.5	760	1730	530	580
1.5	279	550	201	213
2.5	133	256	102	103
3.5	79	13.8	62	62
4.5	53	90	42	42
7.5	23	35.6	18.8	19
15	6.4	8.5	5.58	5.6
22.5	2.87	3.39	2.60	2.73
27.5	1.91	2.07	1.78	1.80
35	1.17	1.22	1.1	1.15
42.5	.77	.75	.76	.78
47.5	.61	.57	.60	.62

Table 19

WHOLE BODY CLOUD SUMBERSION MAN-REM

N	3.08E05
NNE	5.93E05
NE	4.99E05
ENE	E.08E05
E	1.50E05
ESE	1.60E05
SE	2.18E05
SSE	2.17E05
S	5.70E05
SSW	7.60E05
SW	4.60E05
WSW	6.90E05
W	2.16E05
WNW	1.73E05
NW	1.35E05
NNW	1.36E05

Major Contributing Nuclides

I135	30%
I132	19%
I133	12%
I134	9%
I131	5%

Table 20

WHOLE BODY REM/PERSON DUE TO GROUND DEPOSITION FOR SELECTED DIRECTIONS

Average Radius(mi)	SSW	W	NW	N
.5	46.4	93.2	80.3	35.6
1.5	17.4	37.2	31.9	13.2
2.5	8.61	17.6	15.2	6.60
3.5	5.24	10.4	9.03	4.02
4.5	3.58	6.89	6.05	2.77
7.5	1.69	3.17	2.81	1.32
15	.573	1.44	.901	.467
22.5	.28	.647	.395	.244
27.5	.199	.453	.275	.179
35	.136	.179	.178	.123
42.5	.095	.115	.114	.090
47.5	.078	.091	.090	.074

Table 20A

MAN-REM DUE TO GROUND DEPOSITION FOR ONE DAY

N	48,950
NNE	57,180
NE	41,850
ENE	27,140
E	12,270
ESE	12,680
SE	17,590
SSE	17,850
S	58,870
SSW	67,980
SW	35,990
WSW	60,090
W	18,100
WNW	16,740
NW	12,860
NNW	13,160

Table 21

DOSE FACTORS FOR EXPOSURE ON CONTAMINATED GROUND

Isotope	Average	WB Ground Dose Factors $(rem/hr/Ci/m^2)^2$	Skin Dose Factors
KR 85	0	0	0
KR85*	.16	3.0	6.6*
KR87	.82	12.0	15*
KR88	2.21	30.0	39*
SR89	0	0	0
SR90	0	0	0
SR91	.75	14.2	21*
Y90	1.739^3	.01	.013*
Y91	1.21^3	.01	.014*
ZR95	.76	10.0	12.4
ZR97	.24	11.9	23*
Nb95	.77	10.2	13.16
Mo99	.19	3.6	8*
Tc99*	.14	2.0	4.5*
Ru103	.49	7.2	8.4
Ru105	.79	9.0	13.4*
Ru106	.20	3.0	3.6
Rh105	.02	1.4	7
Te129	.07	1.5	2.3*
Te129*	.10	1.5	3.3*
Te131*	1.49	16.8	22.7*
Te132	.28	3.4	4.0
I131	.39	5.6	6.8

* Calculated from average energy at skin depth of 7×10^{-3} cm.

Table 21 continued

Isotope	Modified WB Dose Factors	Modified Skin Dose Factors	Solubility in Cold Water
KR85	0	0	S
KR85*	1.0	2.2	S
KR87	3.3	5.0	S
KR88	10	13	S
SR89	0	0	D
SR90	0	0	D
SR91	4.7	7.0	D
Y90	.003	.004	SS D
Y91	.003	.005	SS D
Zr95	3.3	4.1	I
Zr97	3.6	7.6	I
Nb95	3.4	4.5	I
Mo99	1.2	2.6	I
Tc99*	.66	1.5	I
Ru103	2.4	2.8	D
Ru105	3.0	4.5	D
Ru106	1.0	1.3	D
Rh105	.46	2.3	I
Te129	.5	.76	I
Te129*	.5	1.1	I
Te131*	5.6	7.6	I
Te132	1.1	1.3	I
I131	1.9	2.3	S

S = Soluble I = Insoluble SS = Slightly soluble

D = Decomposes

Table 22

FRACTION OF DISSOLVED NUCLIDES PASSING THROUGH CLASS 3 OR 4 WATER TREATMENT PLANT[1,31]

Isotope	Fraction
KR85	
KR85*	
KR87	
KR88	
SR89	.2
SR90	.2
SR91	
Y90	.2
Y91	
Zr95	.3
Zr97	
Nb95	.3
Mo99	.8
Tc99*	
Ru103	.2
Ru105	
Ru106	.2
Rh105	
Te129	
Te129*	
Te131*	
Te132	.7
I131	.8
Mi131	

Blank = unknown
and assumed = 1

Table 22

Isotope	Fraction
I 132	0
I133	.8
I132	
I135	.2
Mi135	
Xe133	
Xe135	
Cs134	.8
Cs136	
Cs137	.8
Ba140	.2
La140	.2
Ce141	.2
Ce143	.2
Ce144	
Pr143	
Nd147	
Pm147	
Pm149	
Pu238	
Pu239	

Blank = unknown
and assumed = 1

Table 23

HUDSON RIVER DATA

Number	Radius	Sector	Length(mi)	Surface Area(ft^2)	Water Treatment Facility Type
1	7	2	11	1.63E08	4[20]
2	6	2	5.3	8.46E07	4[17]
3	5	3	1.1	1.17E07	4[20]
4	4	3	1.0	1.62E07	0
5	3	3	1.0	2.27E07	0
6	2	3	.7	1.87E07	0
7	2	2	1.0	1.13E07	0
8	1	3	.3	4.32E06	0
9	1	4	.3	6.48E06	0
10	1	5	.3	4.55E06	0
11	1	6	.3	5.40E06	0
12	1	7	.3	5.85E06	0
13	1	8	.4	3.60E06	0
14	2	8	.7	9.72E06	0
15	2	8	1.0	2.11E07	0
16	3	9	1.1	1.84E07	0
17	4	9	1.0	2.17E07	0
18	5	10	1.0	2.27E07	0
19	6	9	5.1	1.36E08	0

Table 24

DRINKING WATER FACILITY DATA[16-21]
(Major Lakes Within 50 Mile Radius)

County	Body of Water	Location Served Population	Surface Area(ft^2)	Total Gallons	Mesh Point Location	Treatment Facility Type	Ref
Ulster	Reservoir 1-4	Kingston 30,000	$2.16x10^6$	$1.4x10^{10}$	7, 10	2	16
Ulster	Lake	Saugerties 6400	$1.13x10^5$	$1.0x10^7$	6, 10	1	16
Ulster	Lake Ashokan	Proposed-Saugerties, Ulster, Hurley, Kingston, Marbletown, Rosendale, Newpaltz, Gardiner, Shawangunk, Plattekill.	$3.38x10^8$	$1.5x10^{12}$	7, 11	1	16
Albany	Alcove Reservoir	Albany	$6.7x10^7$	$1.3x10^7$	8, 1	2	21
Albany	Basic Reservoir	Albany	$1.31x10^6$	$7.2x10^5$	8, 1	2	21
Dutchess	Reservoir	Staatsburg 1000	$4.05x10^5$	$6.0x10^5$	7, 10	2	18
Columbia	Forest Lake	Philmont 1800	$5.23x10^5$	$2.0x10^5$	7, 4	1	18
Columbia	Churchtown Reservoir	Hudson 8700	$9.04x10^6$	$8.0x10^7$	7, 3	2	18
Greene	Coxsackie	Coxsackie 3500	$1.04x10^7$	$2.8x10^8$	7, 2	1	20
Greene	Potuck Reservoir	Catskill 7800	$9.15x10^6$	$2.5x10^8$	5, 14	2	20

Table 24 continued

County	Body of Water	Location Served Population	Surface Area(ft^2)	Total Gallons	Mesh Point Location	Treatment Facility Type	Ref
Greene	Onteora Pond	Tannersville 2500	7.75×10^5	5.5×10^7	7, 14	1	20
Greene	Holister Lake	Athens 1718	7.91×10^5	7.0×10^7	7, 2	1	20

Table 25

WATER SUBMERSION DOSE FACTORS[24]

Isotope	Skin mrem/hr / pCi/l	Whole Body mrem/hr / pCi/l
KR 85	1.8E-07	4.7E-09
KR 85*	5.1E-07	2.8E-07
KR 87	4.6E-06	2.7E-06
KR 88	4.1E-06	3.3E-06
Sr 89	5.4E-07	4.6E-09
Sr 90	1.5E-07	5.4E-10
Sr 91	2.9E-06	1.9E-06
Y 90	9.6E-07	1.3E-08
Y 91	5.7E-07	6.7E-09
Zr 95	1.8E-06	1.5E-06
Zr 97	2.4E-06	1.5E-06
Nb 95	1.6E-06	1.4E-06
Mo 99	2.4E-07	2.1E-07
Tc 99*	2.7E-07	2.4E-07
Ru 103	1.1E-06	8.9E-07
Ru 105	1.8E-06	1.2E-06
Ru 106	1.9E-06	3.8E-07
Rh 105	3.0E-07	1.7E-07
Te 129	7.0E-07	1.9E-07
Te 129*	7.4E-07	2.1E-07
Te 131*	2.7E-06	2.2E-06
Te 132	4.8E-07	4.0E-07
I 131	9.3E-07	6.8E-07
MI 131	9.3E-07	6.8E-07
I 132	5.5E-06	4.4E-06
I 133	1.5E-06	9.6E-07
I 134	5.5E-06	4.2E-06
I 135	4.0E-06	3.3E-06
MI 135*	4.0E-06	3.3E-06
Xe 133	1.1E-07	5.7E-08
Xe 135	7.9E-07	4.5E-07
Cs 134	3.5E-06	2.9E-06
Cs 136	4.8E-06	4.1E-06
Cs 137	1.4E-06	1.0E-06
Ba 140	7.6E-07	4.9E-07
La 140	5.3E-06	4.1E-06
Ce 141	2.4E-07	1.3E-07
Ce 143	1.0E-06	5.7E-07
Ce 144	1.4E-06	8.6E-08
Pr 143	2.8E-07	1.6E-09
Nd 147	5.0E-07	2.8E-07
Pm 147	1.3E-08	7.5E-11
Pm 149	3.5E-07	1.5E-08
Pu 238	4.0E-09	1.5E-10
Pu 239	1.7E-09	1.2E-10

Table 26

WHOLE BODY CLOUD SUBMERSION DOSE FACTORS

Isotope	WASH 1400 converted to mrem/sec Ci/m^3	WASH 1400 Modified by 1/3 Shielding Factor	WASH 1258 Converted to mrem/sec Ci/m^3	WASH 1258 Modified by 1/3 Shielding Factor
KR 85	0	0	.6	.2
KR 85*	36	13	36	12
KR 87	360	130	361	120
KR 88	420	140	417	139
SR 89	0	0	.6	.2
SR 90	0	0	.1	.03
SR 91	160	53	247	82
Y 90	2	.6	1.7	.6
Y 91	2	.6	.9	.3
Zr 95	190	63	190	63
Zr 97	60	20	192	64
Nb 95	180	60	178	59
Mo 99	60	20	31	10
Tc 99	35	12	31	10
Ru 103	110	37	114	38
Ru 105	200	67	150	50
Ru 106	50	16	47	16
Rh 105	5	1.6	22	7
Te 129	18	6	27	9
Te 129*	25	12.5	24	8
Te 131*	375	125	278	93
Te 132	50	17	50	17
I 131	90	30	86	29
I 132	550	183	556	185
I 133	120	40	122	41
I 134	600	200	556	185
I 135	420	140	417	139
MI 135	420	140	417	139
Xe 133	7	2.3	7	2
Xe 135	60	20	58	19
Cs 134	360	120	361	120
Cs 136	460	153	528	176
Cs 137	130	43	131	44
Ba 140	60	20	61	20
La 140	520	173	528	176
Ce 141	16	5.3	16	5
Ce 143	85	28	72	24
Ce 144	4	1.3	11	4
Pr 143	0	0	.2	.1
Nd 147	45	15	36	13
Pm 147	0	0	0	
Pm 149	12	4	2	.6
Pu 238	0	0	.02	.007
Pu 239	0	0	.02	.007

Table 27

CRITICAL ORGAN DOSES
DUE TO CONTAMINATED WATER INGESTION
IN ALCOVE RESERVOIR

Isotope	Concentration (pCi/l)	Critical Organ	Dose Factor to Critical Organ (Rem/Ci)
I 131	2.5E07	Thyroid	1.94E06
Cs 134	9.6E06	Whole Body	5.83E03
Cs 137	3.8E07	Whole Body	8.6E04
BA 140	6.8E06	GI	4.43E05
SR 89	1.8E07	Bone	2.19E05
SR 90	4.3E06	Bone	4.03E06
Ru 103	1.1E08	GI	3.21E04
Ru 106	9.1E07	GI	3.47E05

Isotope	Dose Factor to Whole Body (Rem/Ci)	Dose to Critical Organ (rem) 1 Liter Ingested	Dose to Whole Body (rem) 1 Liter Ingested
I 131	3.53E03	49	.1
CS 134	5.83E03	.1	.1
CS 137	8.6E04	3.3	3.3
BA 140	1.3E03	3.0	.01
SR 89	8.78E03	3.94	.16
SR 90	1.77E06	14.3	7.6
Ru 103	8.64E01	3.5	.01
Ru 106	4.43E01	31.6	.004

Table 28

CRITICAL ORGAN DOSES DUE TO INGESTION OF 1 LITER OF MILK AT VARIOUS TIMES AFTER THE ACCIDENT

Cows are assumed to be fed contaminated feed for the duration of time of interest. Distance from the reactor is 2-3 miles north.

Isotope	Dose Factor (Rem/Ci)	Critical Organ	Dose (rem) Day 1	Day 11
^{89}Sr	2.19×10^5	Bone	19.5	10.1
^{90}Sr	4.03×10^6	Bone	84.6	48.4
^{99}Mo	1.93×10^4	GI	6.6	.33
^{129}Te	2.44×10^4	GI	0	0
^{131}I	1.94×10^6	Thyroid	980	254
^{134}Cs	5.83×10^3	WB	1.34	.82
^{136}Cs	7.55×10^3	WB	.36	.13
^{137}Cs	8.6×10^4	WB	80	47
^{140}Ba	4.43×10^5	GI	8.4	2.9

Isotope	Dose (rem) Day 21	Day 31	Day 41	Day 51
^{89}Sr	5.3	2.6	1.4	.72
^{90}Sr	29.4	17.3	10.1	6.05
^{99}Mo	.017	.0009	.04mrem	0
^{129}Te	0	0	0	0
^{131}I	63	16	4.12	1.03
^{134}Cs	.47	.27	.16	.09
^{136}Cs	.044	.015	.0054	.0019
^{137}Cs	27	16	9.5	5.76
^{140}Ba	1.02	.354	.12	.043

Table 29

CRITICAL ORGAN DOSES DUE TO INGESTION
OF 1 LITER OF MILK AT VARIOUS TIMES AFTER THE ACCIDENT

Cows are assumed to be fed uncontaminated feed after 1 day's ingestion of contaminated forage. Distance from the reactor is 2-3 miles north.

Isotope	Dose Factor (Rem/Ci)	Critical Organ	Dose (rem) Day 1	Day 11
^{89}Sr	2.19×10^{5}	Bone	19.5	.28
^{90}Sr	4.03×10^{6}	Bone	84.6	1.61
^{99}Mo	1.93×10^{4}	GI	6.6	.001
^{129}Te	2.44×10^{4}	GI	0	0
^{131}I	1.94×10^{6}	Thyroid	980	3.3
^{134}Cs	5.83×10^{3}	WB	1.34	.026
^{136}Cs	7.55×10^{3}	WB	.36	.002
^{137}Cs	8.6×10^{4}	WB	80	1.55
^{140}Ba	4.43×10^{5}	GI	8.42	.053

Isotope	Day 21	Day 31	Dose (rem) Day 41	Day 51
^{89}Sr	.15	.079	.042	.022
^{90}Sr	.967	.605	.359	.218
^{99}Mo	0	0	0	0
^{129}Te	0	0	0	0
^{131}I	.83	.21	.05	.014
^{134}Cs	.015	.0093	.0055	.0034
^{136}Cs	.8mrem	.3mrem	.1mrem	0
^{137}Cs	.95	.56	.34	.21
^{140}Ba	.019	.0066	.0023	.8mrem

Table 30

PROBABILITY OF WIND BLOWING IN DIRECTION LISTED (%) FOR ALL STABILITY CLASSES[13]

N	23.58
NNE	10.85
NE	2.99
ENE	1.62
E	1.89
ESE	4.05
SE	6.17
SSE	8.28
S	11.18
SSW	12.6
SW	5.58
WSW	2.06
W	1.31
WNW	1.1
NW	1.59
NNW	5.15

Table 31

FRESH WATER FISH CONCENTRATION FACTORS

Isotope	pCi/Kg/pCi/l[24]
KR 85	1
KR 85*	1
KR 87	1
KR 88	1
SR 89	30
SR 90	30
SR 91	30
Y 90	25
Y 91	25
Zr 95	330
Zr 97	330
Nb 95	30000
Mo 99	10
Tc 99*	15
Ru 103	10
Ru 105	10
Ru 106	10
Rh 105	10
Te 129	400
Te 129*	400
Te 131*	400
Te 132	1000[31]
I 131	15
MI 131	15[24]

Values vary considerably in the literature. Most conservative values used.

1 [24] pp. 50-52 unless otherwise noted.

2 Value from [31] p 114.

3 Assumed from [31].

4 Assumed from [24].

Table 32

COEFFICIENTS FOR MILK CONCENTRATION[3]

Isotope	Concentration Factor (B) pCi/Kg per pCi/Kg Dry Soil	Coefficient of Transfer From Diet to Milk (pCi/1 per pCi/day)
KR 85	1.0E-00	2E-2
KR 85*	1.0E-00	2E-2
KR 87	1.0E-00	2E-2
KR 88	1.0E-00	2E-2
SR 89	2.0E-1	1E-3
SR 90	2.0E-1	1E-3
SR 91	2.0E-1	1E-3
Y 90	1.0E-1	1E-5
Y 91	1.0E-1	1E-5
Zr 95	1.7E-4	5E-6
Zr 97	1.7E-4	5E-6
Nb 95	9.4E-3	2.5E-3
Mo 99	1.3E-1	7.5E-3
Te 99*	1.0E-2	2.5E-2
Ru 103	1.0E-2	1.E-6
Ru 105	1.0E-2	1.E-6
Ru 106	1.0E-2	1.E-6
Rh 105	2.0E-10	1.E-2
Te 129	1.3E-00	1.E-3
Te 129*	1.3E-00	1.E-3
Te 131*	1.3E-00	1.E-3
Te 132	1.3E+0	1.E-3
I 131	2E-2	1.E-2
MI 131	2.0E-2	1.E-2
I 132	2E-2	1.E-2
I 133	2E-2	1.E-2
I 134	2.0E-2	1.E-2
I 135	2E-2	1.E-2
MI 135	2.0E-2	1.E-2
Xe 133	1.0E-00	2.E-2
Xe 135	1.0E-00	2.E-2
Cs 134	2E-3	5.E-3
Cs 136	2.0E-3	5.E-3
Cs 137	2E-3	5.E-3
Ba 140	5E-3	6.E-4
La 140	2.5E-3	5.E-6
Ce 141	5E-4	2.E-5
Ce 143	5.0E-4	2.E-5
Ce 144	5E-4	2.E-5
Pr 143	1.0E-00	5.E-6
Nd 147	1.0E-00	5.E-6
Pm 147	1.0E-00	5.E-6
Pm 149	1.0E-00	5.E-6
Pu 238	1.0E-11	1.5E-6
Pu 239	1.0E-11	1.5E-6

PART VII

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PART VIII

APPENDIX

Listing of the MODAIREM Computer Code

Approximately half of this code is taken from the AIREM Computer Code written by J. A. Martin, C. B. Nelson, and P. A. Cuny. There are several minor additions in the body of the AIREM Code and the original code essentially ends with statement Number 1550 in the main program plus function SIGZ. A listing of the code in its entirety follows.

```
C
C
      DIMENSION FREQ(16,6),UBAR(16,6),SIGMZ(6,12),X(12),FACIL(5),
     1          QL(20),ISO(20),DCF(20),XLMDA(20),DMIL(12,16,20),
     2          THYDOS(12,16),BONDOS(12,16),SKNDOS(12,16),DPWB(12,16),
     3          DPTHY(12,16),DPBON(12,16),DPSKN(12,16),DPWBM(12),
     4          DPSKNM(12),WBDOS(12,16),DECON(20),
     5          DPTHYM(12),XLOW(12),XUP(12),Y(13),POP(12,16),
     6          DMIJL(12,16,6,20),CHIOQ(12,16,6,20),DPBONM(12),PV(6,4),
     7          TQM(13),AREA(12),QGMI(12,16),QGAMI(12,16),HV(6,4),
     8          QG(12,6),PDEPV(16,6),HDEPV(16,6),F(13),
     9          LATWT(20),CRTORG(20),NDEP(20)
      DIMENSION NGAMMA(20),NDTR(20),AGAM(20,10),ABUN(20,10)
      DIMENSION GAMEN(32),SIGZM(32),DOSEI(32,32),ETITLE(20)
      DIMENSION DIR(16),CHIOQS(12)
      DIMENSION WTQGM(13),WQG(12,6),WQGAMI(12,16),WQGMI(12,16)
      DIMENSION CLDTIM(12,16),FX(12,16),ACTDEN(12,16,20),DR(12,16)
      DIMENSION TD(12,16),POPUL(12,16)
      DIMENSION XLAMBD(20)
```

```
      DIMENSION FX2(12,16),POP2(12,16)
C
      REAL MONTHS
C
      DATA DIR/'N   ','NNE ','NE  ','ENE ','E   ','ESE ','SE  ','SSE ',
     *         'S   ','SSW ','SW  ','WSW ','W   ','WNW ','NW  ','NNW '/
C
      EQUIVALENCE(CHIOQ(1,1,1,1),DMIJL(1,1,1,1))
C     EQUIVALENCE(WBDOS(1,1),THYDOS(1,1),SKNDOS(1,1),BONDOS(1,1),
C    1QGMI(1,1))
C     EQUIVALENCE(DPWB(1,1),DPTHY(1,1),DPBON(1,1),DPSKN(1,1),OGAMI(1,1))
C     EQUIVALENCE(DPWBM(1),DPTHYM(1),DPBONM(1),DPSKNM(1))
      EQUIVALENCE(Y(1),F(1),TQM(1))
C
      PI=3.141593
C
C     READ VARIABLE INPUT DATA
C
C
      DO 9001 MM=1,12
      DO 9001 II=1,16
      DO 9001 LL=1,20
      POPUL(MM,II)=0.
 9001 ACTDEN(MM,II,LL)=0.
      WRITE(3,100)
  100 FORMAT(1H1,T32,'PROGRAM AIREM04'//
     *        1X,T12,'FOR INFORMATION REGARDING THIS PROGRAM,',
     *                ' CONTACT:'//
     *        1X,T20,'ENVIRONMENTAL PROTECTION AGENCY'/
     *        1X,T20,'OFFICE OF RADIATION PROGRAMS'/
     *        1X,T20,'FIELD OPERATIONS DIVISION'/
     *        1X,T20,'401 M ST SW'/
     *        1X,T20,'WASHINGTON, DC'/
     *        1X,T20,'20460')
      WRITE(3,380)
      READ(1,110)(FACIL,MONTHS,MONTH1,NYR1,MONTH2,NYR2,ETHERM)
      WRITE(3,390)
      WRITE(3,112)(FACIL,MONTHS,MONTH1,NYR1,MONTH2,NYR2,ETHERM)
  110 FORMAT(5A4,F5.0,1X,A4,I5,1X,A4,I5,F10.0)
  112 FORMAT(1X,5A4,F5.2,1X,A4,I5,1X,A4,I5,F10.0)
  120 READ(1,300) I,J,M,L,H,SIGMAX,HOLDUP,RAINF,WASHCO
      WRITE(3,400)
      WRITE(3,300) I,J,M,L,H,SIGMAX,HOLDUP,RAINF,WASHCO
C
C     READ/WRITE WIND FREQUENCY (%) BY STABILITY CLASS. FIRST LINE
C     IS NORTH, SECOND IS NNE, ETC.
C
      READ(1,310)((FREQ(II,JJ),JJ=1,J),II=1,I)
      WRITE(3,410)
      TOTFRQ=0.
      DO 122 II=1,I
      C1=0.
      DO 121 JJ=1,J
  121 C1=C1+FREQ(II,JJ)
      TOTFRQ=TOTFRQ+C1
  122 WRITE(3,124) (DIR(II),(FREQ(II,JJ),JJ=1,J),C1)
  124 FORMAT(1X,A4,7F10.2)
C
C     READ/WRITE WIND SPEEDS BY STABILITY CLASS. FIRST LINE IS N,
C     SECOND IS NNE, ETC.
```

```
C
      READ(1,310)((UBAR(II,JJ),JJ=1,J),II=1,I)
      WRITE(3,420)
      WRITE(3,126)(DIR(II),(UBAR(II,JJ),JJ=1,J),II=1,I)
  126 FORMAT(1X,A4,6F10.2)
C
C     READ/WRITE POPULATIONS CLOCKWISE BY SECTOR
C     FIRST LINE IS POPULATION IN FIRST 8 SECTORS IN
C     INNER ANNULUS.
C
      DO 130 MM=1,M
  130 READ(1,320) (POP(MM,II),II=1,I)
  131 NCOUNT=0
  133 CONTINUE
      WRITE(3,430)
      IF(NCOUNT.GT.0)GO TO 144
      DO 140 MM=1,M
      WRITE(3,132) MM,(POP(MM,II),II=1,I)
  132 FORMAT(1X,I2,(T5,8F10.0))
      C1=0.
      DO 139 II=1,I
  139 C1=C1+POP(MM,II)
  140 WRITE(3,141) C1
  141 FORMAT(1X,T5,F10.0)
      GO TO 147
  144 CONTINUE
      IF(NEVAC.EQ.1)GO TO 147
      DO 146 MM=1,M
      WRITE(3,132)MM,(POPUL(MM,II),II=1,I)
      C1=0.
      DO 145 II=1,I
  145 C1=C1+POPUL(MM,II)
  146 WRITE(3,141)C1
  147 CONTINUE
      IF(NEVAC.LT.0)GO TO 6610
      IF(NCOUNT.EQ.0)GO TO 6610
      MMM=M/2
      DO 6602 MM=1,MMM
      WRITE(3,132)MM,(POPUL(MM,II),II=1,I)
      C1=0.
      DO 6603 II=1,I
 6603 C1=C1+POPUL(MM,II)
 6602 WRITE(3,141)C1
      MMMM=MMM+1
      DO 6601 MM=MMMM,M
      WRITE(3,132)MM,(POP(MM,II),II=1,I)
      C1=0.
      DO 6604 II=1,I
 6604 C1=C1+POP(MM,II)
 6601 WRITE(3,141)C1
 6610 CONTINUE
      IF(NCOUNT.GT.0)GO TO 561
      READ(1,330)((X(MM),XLOW(MM),XUP(MM)),MM=1,M)
      WRITE(3,440)
      WRITE(3,142)(MM,(X(MM),XLOW(MM),XUP(MM)),MM=1,M)
  142 FORMAT(1X,I2,1X,3F10.0)
C
C     READ EXPANSION COEFFICIENTS FOR PARTICULATES (P) AND HALOGENS (H).
C
C    THE INPUT DATA FORMAT CAN BE USED FOR A DATA FIT UP TO FOUR TERMS.
```

```
C      MANY FSAR"S ASSUME THAT PARTICULATE AND HALOGEN DEPOSITIONS ARE
C      DIFFERENT. DATA IN MET. AND AT. ENERGY SHOW A COMPLETE OVERLAP,
C     WITH A LARGE SPREAD IN BOTH SETS OF DATA.
C     MANY FSAR"S ASSUME DEPOSITION VELOCIYY IS PROPORTIONAL TO WIND
C      SPEED. DATA IN MET. AND AT. ENERGY INDICATES THE OPPOSITE TREND.
C      IN THIS LIGHT AND WHEN ACTUAL DATA IS LACKING, A SUGGESTION IS
C      TO USE A CONSTANT 0.01 METER/SEC FOR BOTH HALOGEN AND PARTICU-
C     LATES. (FOLLOWED BY THREE BLANK INPUT CARDS IN EACH CASE).
C
C      FORMAT IS AS FOLLOWS
C
C          CLASS/ A      B      C      D      E      F
C      TERM                                                    INDICES
C    CONSTANT       H11    H21    H31    H41    H51    H61         (CLASS,KOF)=(JJ,K
C    LINEAR         H12    H22    H32    H42     .      .
C    QUADRATIC      H13    H23    H33     .      .      .
C    CUBIC          H14    H24     .      .      .     H64
C                                                      H6,KKOF
C
C      DEPOSITION VELOCITY IN SECTOR 1 FOR STABILITY CLASS A  IS
C      DEPV(1,1) = H11 + H12 *UBAR(1,1) + H13 * UBAR(1,1)**2
C                                 + H14 * UBAR(1,1)** 3      (M/SEC)
C
       KKOF = 4
       READ(1,370)((PV(JJ,KOF),JJ=1,J),KOF=1,KKOF)
       READ(1,370)((HV(JJ,KOF),JJ=1,J),KOF=1,KKOF)
       WRITE(3,150)
   150 FORMAT(68HOPARTICULATE AND HALOGEN DEPOSITION VELOCITY EXPANSION C
      1OEFFICIENTS.)
       WRITE(3,370)((PV(JJ,KOF),JJ=1,J),KOF=1,KKOF)
       WRITE(3,370)((HV(JJ,KOF),JJ=1,J),KOF=1,KKOF)
C
C      READ NUMBERS OF SETS OF ORGANS.
C
       READ(1,340)NWB,NTHY,NBON,NSKN
       WRITE(3,450)
       WRITE(3,340)NWB,NTHY,NBON,NSKN
C
C
C      READ AND WRITE ISOTOPE DATA
C      READ AND WRITE QL'S
C      THE ISOTOPE CARDS ARE FORMATTED TO CONTAIN DATA TO BE
C      REQUIRED FOR LATER VERSIONS OF THIS PROGRAM. SUCH ISOTOPE CARDS
C      NEED BE PUNCHED ONLY ONCE TO COMPILE A LIBRARY OF SAME.
C      THEREAFTER, ONLY THE QL'S NEED BE PUNCHED FOR EACH PROBLEM.
C
C      WHEN USING THE SEMI-INFINITE CLOUD APPXOXIMATION,
C      THE DCF IS :( THE DOSE COMMITTMENT FACTOR IN MILLIREM/YR)
C      DIVIDED BY (THE ICRP 2 MPCA TIMES 3.157 E+07 SEC/YR).
C          FOR EXTERNAL GAMMA WHOLE BODY AND EXTERNAL BETA SKIN
C      DOSE  DCF = 250 EBAR, WHERE EBAR IS THE AVERAGE GAMMA
C      OR BETA ENERGY (MEV) PER DISINTEGRATION, RESPECTIVELY. SEE AEC
C      SAFETY GUIDES 3 AND 4.
C
C      GAMMA ENERGIES AND ABUNDANCES ARE READ AND THE FINITE CLOUD
C       CALCULATION IS PERFORMED IF NGAMMA IS NOT ZERO.
C       REF. M.E. MEEK AND R.S. GILBERT  SUMMARY OF BETA AND
C       GAMMA ENERGY AND INTENSITY DATA.  NEDO-12037, JAN 1970.
C       G.E. VALLECITOS NUCLEAR CENTER, PLEASANTON, CALIF.
C
```

```
      WRITE(3,460)
      DO 200 LL=1,L
      READ(1,160) ISO(LL),LATWT(LL),CRTORG(LL),DCF(LL),XLMDA(LL),
     1            NDEP(LL),NGAMMA(LL),NDTR(LL)
      WRITE(3,162) LL,ISO(LL),LATWT(LL),CRTORG(LL),DCF(LL),XLMDA(LL),
     1            NDEP(LL),NGAMMA(LL),NDTR(LL)
  160 FORMAT(3(1X,A4),F10.1,E10.2,3I5)
  162 FORMAT(1X,I2,1X,3(1X,A4),F10.1,E10.2,3I5)
C     READ AND WRITE GAMMA ENERGIES AND ABUNDANCES
      IF(NGAMMA(LL).EQ.0) GO TO 190
      NG=NGAMMA(LL)
      READ(1,170)(AGAM(LL,IG),ABUN(LL,IG),IG=1,NG)
  170 FORMAT(12F6.0)
      WRITE(3,180)(AGAM(LL,IG),ABUN(LL,IG),IG=1,NG)
  180 FORMAT(1X,3X,5(1X,F9.3,F8.4))
  190 READ (1,350) QL(LL),DECON(LL)
  200 WRITE(3,290) (QL(LL),DECON(LL))
      READ(1,202) ETITLE
  202 FORMAT(20A4)
      WRITE(3,204) ETITLE
  204 FORMAT(1H0,20A4)
      READ (1,210) NGAM,NSIG
  210 FORMAT(20I4)
      WRITE(3,220) NGAM,NSIG
  220 FORMAT(1X,'NGAM,NSIG'/1X,I4,1X,I4)
      READ (1,250) (GAMEN(IN),IN=1,NGAM)
      WRITE(3,230) (GAMEN(IN),IN=1,NGAM)
  230 FORMAT(1X,'GAMEN IN MEV'/(1X,8E12.4))
      READ (1,250) (SIGZM(IN),IN=1,NSIG)
      WRITE(3,240) (SIGZM(IN),IN=1,NSIG)
  240 FORMAT(1X,'SIGZM IN METERS'/(1X,8E12.4))
  250 FORMAT(8E10.4)
      DO 260 II=1,NGAM
  260 READ (1,250) (DOSEI(II,JJ),JJ=1,NSIG)
      DO 270 II=1,NGAM
  270 WRITE(3,280) GAMEN(II),(DOSEI(II,JJ),JJ=1,NSIG)
  280 FORMAT(1X,'DOSEI IN RAD METERS**2 PER CURIE SEC AT',F6.3,' MEV'/
     1       (1X,8E12.4))
  290 FORMAT( 1X,4X,
     1       F13.3,3X,7H CURIES,5X,7HDECON= ,E10.3/)
  300 FORMAT(4I5,2F10.2,3E10.2)
  310 FORMAT(6F10.2)
  320 FORMAT(8F10.0)
  330 FORMAT(3F10.0)
  340 FORMAT(4I5)
  350 FORMAT(F10.6,E10.3)
  360 FORMAT(E10.2)
  370 FORMAT(6E10.2)
  380 FORMAT (1H0,30X,'INPUT DATA:')
  390 FORMAT(76H0FACILITY, NO.MONTHS OF DATA, PERIOD, THERMAL ENERGY GEN
     1ERATED DURING PERIOD)
  400 FORMAT(1H0,'NO. SECTORS, STABILITY CLASSES, RADII AND ISOTOPES,',
     1          ' STACK HEIGHT IN METERS, INVERSION LID'/
     2       1X,'HOLDUP IN DAYS,RAINFALL FRACTION,WASHOUT COEFFICIENT',
     3          ' (1/SEC)')
  410 FORMAT(1H0,'WIND FREQUENCY IN PERCENT BY STABILITY CLASS FOR',
     1          ' EACH SECTOR AND TOTAL FREQUENCY FOR SECTOR'/
     2       1X,'DIR',8X,'A',9X,'B',9X,'C',9X,'D',9X,'E',9X,'F',
     3          7X,'TOTAL')
  420 FORMAT(1H0,'WIND SPEED IN METERS PER SECOND BY STABILITY CLASS ',
```

```
     1            'FOR EACH COMPASS DIRECTION'/
     2         1X,'DIR',8X,'A',9X,'B',9X,'C',9X,'D',9X,'E',9X,'F')
  430 FORMAT(1H1,'POPULATIONS IN SECTOR SEGMENTS, TWO LINES PER RADIUS',
     *            ' (READ CLOCKWISE), AND TOTAL POPULATION IN ANNULI'/
     *         1X,'MM',1X,'N/S/TOTAL',3X,'NNE/SSW',5X,'NE/SW',3X,
     *            'ENE/WSW',7X,'E/W',3X,'ESE/WSW',5X,'SE/NW',3X,
     *            'SSE/NNW')
  440 FORMAT(1H0,'DISTANCES IN METERS: MIDPOINT, LOWER AND UPPER OF',
     *            ' BINS'/
     *         1X,'MM',8X,'X',7X,'XLOW',7X,'XUP')
  450 FORMAT(97H0NUMBER OF ISOTOPES PER SET OF CRITICAL ORGANS. (FOUR SE
     1TS OF ORGANS, TWENTY ISOTOPES, MAX. TOTAL)
  460 FORMAT(1H0,'ISOTOPE DATA: ISOTOPE, CRITICAL ORGAN, MRAD/SEC PER ',
     *            'CI/METER**3, DECAY CONSTANT (1/SEC),',
     *            'NDEP, NGAMMA, NDTR'/
     *         1X,T16,'AGAM,ABUN: GAMMA ENERGY (MEV) AND ABUNDANCE ',
     *            '(NGAMMA PAIRS)'/
     *         1X,T16,'ACTIVITY RELEASED (CURIES) DURING PERIOD,',
     *            ' NUCLIDE DECONTAMINATION FACTOR'/
     *         1X,'LL')
C
C
      N1=NWB+NTHY+NBON+NSKN-L
      IF(N1) 470,490,470
  470 WRITE(3,480)
  480 FORMAT(1X,'THE NUMBER OF ISOTOPE CARDS MUST MATCH L. IF AN ISOTOPE
     1 IS ASSOCIATED WITH TWO ORGANS IT IS TO BE COUNTED TWICE.')
      GO TO 1551
  490 IF(J-6)500,520,500
  500 WRITE(3,510)
  510 FORMAT(1H1,12H J MUST BE 6)
      GO TO 1551
C
C     COMPUTE VALUES OF SIGMZ
C
  520 DO 530 JJ=1,J
      DO 530 MM=1,M
      Y(MM)=X(MM)*0.001
  530 SIGMZ(JJ,MM)=SIGZ(JJ,Y(MM))
C
      WRITE(3,540)
  540 FORMAT(1H1,30X,'OUTPUT DATA:'/
     *        1H0,2X,'SIGMA ZEE''S BY STABILITY CLASS AND RADIUS'/
     *         1X,3X,2H A,8X,2H B,8X,2H C,8X,2H D ,8X,2H E,8X,2H F/)
  550 WRITE(3,370)((SIGMZ(JJ,MM),JJ=1,J),MM=1,M)
C
C     CALCULATE DECAYED CHI OVER Q IN EACH SECTOR SEGMENT,
C     FOR EACH STABILITY CLASS AND FOR EACH ISOTOPE AND STORE.
C   DIFFUSION EQUATION IS EQ. 3.144 IN SLADE,' MET. AND AT. ENERGY.'
C   (1968) T10-24190, NTIS, US DEPT COMMERCE, SPRINGFIELD, VA, 22151
C     THIS PROGRAM SETS CHI OVER Q TO ZERO IF FREQ OR UBAR ARE LESS THAN
C     0.01  .
C
C     CONVERT HOLDUP FROM DAYS TO SECONDS.
      HOLD=HOLDUP*8.64E4
C    CONVERT ORIGINAL CURIE INVENTORY TO STACK RELEASE INVENTORY
C     BY APPLYING HOLDUP AND DECONTAMINATION.
      DO 560 LL=1,L
C     GO THROUGH LIST BACKWARDS TO SIMPLIFY INGROWTH CALCULATIONS
      IL=L+1-LL
```

```
C      DECAY ORIGINAL INVENTORY
       QL(IL)=QL(IL)*EXP(-XLMDA(IL)*HOLD)
C      CHECK FOR AND GROW IN DAUGHTERS
       IF ( NOTR(IL).NE.0) QL(IL)=QL(IL)+QL(IL-1)*XLMDA(IL)/(XLMDA(IL)
     1                          -XLMDA(IL-1))*(EXP(-XLMDA(IL-1)*HOLD)
     2                          -EXP(-XLMDA(IL)*HOLD))
C      APPLY DECONTAMINATION FACTOR
       IF (DECON(IL).LT.1.) DECON(IL)=1.0
       QL(IL)=QL(IL)/DECON(IL)
C      SET RELEASES OF LESS THAN ONE MICROCURIE TO ZERO TO
C      AVOID UNDERFLOWS.
       IF (QL(IL).LT.1.E-6) QL(IL)=0.
  560  CONTINUE
C
  561  CONTINUE
       XI=I*1.0/(16.)
       DO 600 LL=1,L
       DO 600 II=1,I
       DO 600 JJ=1,J
       DO 600 MM=1,M
       IF(FREQ(II,JJ)-0.01)580,580,570
  570  IF(UBAR(II,JJ)-0.01)580,580,590
  580  CHIOQ(MM,II,JJ,LL)=0.0
       GO TO 600
  590  IF(SIGMAX.LT.1.) SIGMAX=1.E+4
       SIGMA=SIGMZ(JJ,MM)
       IF(SIGMA.GT.SIGMAX) SIGMA=SIGMAX
       ARG=H*H/(2.*SIGMA*SIGMA)
       IF(ARG.GT.100.) ARG=100.
       DENOM=SIGMA*UBAR(II,JJ)*X(MM)
       DECAY=EXP((-1.)*(XLMDA(LL))*X(MM)/(UBAR(II,JJ)))
       CHIOQ(MM,II,JJ,LL)=(0.0203)*FREQ(II,JJ)*EXP(-ARG)*XI*DECAY/DENOM
  600  CONTINUE
       IF(NCOUNT.NE.0)GO TO 611
C
C      ********* WRITE OUT CHI/Q SUMMED OVER STABILITY CLASSES **********
C
       WRITE(3,2110)
       WRITE(3,2120) (X(MM),MM=1,M)
       DO 2020 II=1,I
       DO 2010 MM=1,M
       CHIOQS(MM)=0.
       DO 2010 JJ=1,J
       LL=1
       IF(FREQ(II,JJ).LE.0..OR.UBAR(II,JJ).LE.0.) GO TO 2010
       CHIOQS(MM)=CHIOQS(MM)+CHIOQ(MM,II,JJ,LL)
     *            *EXP(XLMDA(LL)*X(MM)/UBAR(II,JJ))
 2010  CONTINUE
 2020  WRITE(3,2130) DIR(II),(CHIOQS(MM),MM=1,M)
C
 2110  FORMAT(1H0,4X,'CHI/Q SUMMED OVER STABILITY CLASSES')
 2120  FORMAT(1H0,56X,'DISTANCE (METERS)'/1X,'DIR',12F10.0/)
 2130  FORMAT(1X,A4,12(1PE10.2))
C
C      CALCULATE DEPOSITION VELOCITIES AND STORE.
C
       DO 610 II = 1,I
       DO 610 JJ = 1,J
       HDEPV(II,JJ)=HV(JJ,1) + HV(JJ,2)* UBAR(II,JJ) + HV(JJ,3) * UBAR(
     1II,JJ) ** 2 + HV(JJ,4)* UBAR(II,JJ) ** 3
```

```
  610 PDEPV(II,JJ)=PV(JJ,1) + PV(JJ,2)* UBAR(II,JJ) + PV(JJ,3) * UBAR(
     1II,JJ) ** 2 + PV(JJ,4)* UBAR(II,JJ) ** 3
C
C     CALCULATE AREAS OF SECTOR SEGMENTS AND STORE.
C
  611 CONTINUE
      XXI = (1.0) * I
      DO 640 MM=1,M
      AREA(MM)=(3.1416)* (XUP(MM)**2 - XLOW(MM)**2)/(XXI)
      C=AREA(MM)-1.0
      IF(NCOUNT.NE.0)GO TO 641
      IF(C) 620,620,640
  620 WRITE(3,630)
  630 FORMAT(51H ONE AREA IS TOO SMALL. CHECK X, XUP,AND XLOW DATA.)
  640 CONTINUE
C
C     DO DEPOSITION AND CLOUD DEPLETION.
C
C     DRY DEPOSITION:
C     CLOUD DEPOSITION AND DEPLETION ARE TREATED USING A SIMPLE MODEL.
C     DEPOSITION STARTS AT THE FIRST (INNER) RADIUS. THE TOTAL ACTIVITY
C     DEPOSITED ON THE GROUND IS CALCULATED ASSUMING A UNIFORM RATE OF
C     DEPOSITION OVER THE ENTIRE SECTOR SEGMENT. CHI OVER Q AT THE
C     SECOND RADIUS IS DEPLETED BY THE FRACTION ON THE GROUND AT THE
C     FIRST RADIUS. THIS PROCESS OF DEPOSITION AND DEPLETION CONTINUES
C     OUT TO THE LAST RADIUS IN THE SECTOR.
C     THIS ROUTINE IS ESSENTIALLY THE SAME AS CALLED FOR BY  EQUATIONS
C     5.44 THRU 5.48 IN METEOROLOGY AND ATOMIC ENERGY (TID-24190),
C     EXCEPT HERE THE DEPOSITION AND DEPLETION DO NOT VARY CONTINUOUSLY
C     WITH DISTANCE AS DOES EQ. 5.48.
C
      CONTINUE
C
C     WET DEPOSITION:
C     WET DEPOSITION IS TREATED USING THE SECTOR AVERAGED ANALOG OF
C     EQUATIONS 5.63 TO 5.65 IN MET. AND AT. ENERGY 1968. THIS
C     IMPLIES THAT WET DEPOSITION IS PROPORTIONAL TO THE ACTIVITY
C     PER SQUARE METER ABOVE THE GROUND, THE PROPORTIONALITY
C     CONSTANT BEING CALLED WASHCO HEREIN. SINCE WET DEPOSITION
C     IS A FIRST ORDER PROCESS, CLOUD DEPLETION IS SIMPLY
C     EXPONENTIAL. WET DEPOSITION IS TREATED INDEPENDENTLY OF ALL DOSE
C     CALCULATIONS. ALTHOUGH THE CLOUD IS DEPLETED BY WASHOUT DURING
C     THE WASHOUT CALCULATIONS, STORED CHI OVER Q'S ARE NOT. IF AN
C     UNNORMALIZED WINDROSE IS USED, I.E. THE SUM OF THE WIND FREQUEN-
C     CIES IS MUCH LESS THAN 1.0, RAINF SHOULD BE ENTERED AS 1.E+00. IF
C     A NORMALIZED ANNUAL WIND ROSE IS USED, I.E. THE SUM OF THE WIND
C     FREQUENCIES IS 1.0, RAINF SHOULD BE THE DECIMAL FRACTION (NOT
C     PERCENT) OF THE TIME IT RAINS. DEFAULT VALUES FOR RAINF AND WASHCO
C     ARE 5.E-02 AND 2.E-04 1/SEC RESPECTIVELY FOR A MODERATELY WET
C     CLIMATE AND PARTICLE DIAMETERS OF SEVERAL MICRONS. SEE MET AND AT
C     E FOR DETAILS.
  641 CONTINUE
      DO 900 LL=1,L
      IF(NDEP(LL).LE.0) GO TO 900
      IF(NDTR(LL).EQ.0.AND.QL(LL).EQ.0.) GO TO 900
      IF(NDTR(LL).EQ.1.AND.QL(LL).EQ.0..AND.QL(LL-1).EQ.0.) GO TO 900
  650 C5 = 0.0
      C8=0.
      DO 800 II=1,I
      DO 740 JJ=1,J
```

```
      DO 740 MM=1,M
      F(1) = 1.0
C     CHECK FOR CHIOQ EQUALS ZERO
      IF(FREQ(II,JJ).GT.0..AND.UBAR(II,JJ).GT.0.) GO TO 670
      QG(MM,JJ)=0.0
      WQG(MM,JJ)=0.0
      F(MM+1)=0.
      GO TO 740
  670 K1 = MM
      C=2.
C    SINCE CHIOQ INCLUDES DECAY THE DAUGHTER QS'S ARE GROWN BACK TO THE
C    . DAUGHTER INGROWTH IS ADDED TO THE INPUT DAUGHTER STRENGTH.
      QS=QL(LL)
      IF (NDTR(LL).NE.0) QS=QS+QL(LL-1)*XLMDA(LL)
     1                      /(XLMDA(LL)-XLMDA(LL-1))
     2                      *(EXP((XLMDA(LL)-XLMDA(LL-1))*X(MM)
     3                      /UBAR(II,JJ))-1.0)
C       PICK UP FACTORS 1 - F(2) -F(3)-.......... -F(MM)
      DO 680 MM1=1,K1
  680 C=C-F(MM1)
C     THE FOLLOWING CONSERVES (Q*FREQ).
      IF(C) 690,690,700
  690 QG(MM,JJ)=0.0
      CHIOQ(MM,II,JJ,LL)=0.0
      MPLS1=MM+1
      F(MPLS1)=2.0
      GO TO 740
C     THE FOLLOWING STEP REPLACES THE OLD CHI OVER Q
C     WITH THE DEPLETED ONE
  700 CHIOQ(MM,II,JJ,LL) = C * CHIOQ(MM,II,JJ,LL)
      IF(NDEP(LL).GE.2) GO TO 720
C     DO PARTICULATE DEPOSITION AND DEPLETION.
  710 QG(MM,JJ)=CHIOQ(MM,II,JJ,LL)*QS*AREA(MM)*PDEPV(II,JJ)
      GO TO 730
C     DO HALOGEN DEPOSITION AND DEPLETION
  720 QG(MM,JJ)=CHIOQ(MM,II,JJ,LL)*QS*AREA(MM)*HDEPV(II,JJ)
  730 MPLS1 = MM+1
      QIJ=QS*FREQ(II,JJ)*0.01
      F(MPLS1)= QG(MM,JJ)/(QIJ)
C
C     CALCULATE WET DEPOSITION
C
      IF(WASHCO.LE.0..OR.RAINF.LE.0.) GO TO 740
      DECAY=EXP(-XLMDA(LL)*X(MM)/UBAR(II,JJ))
      DENOM=UBAR(II,JJ)*X(MM)*2*3.1416/I
      WQG(MM,JJ)=(RAINF*WASHCO*FREQ(II,JJ)/DENOM)*QS*AREA(MM)*DECAY*0.01
     **EXP(-WASHCO*X(MM)/UBAR(II,JJ))
C
C     (LAST TERM INCLUDES CLOUD DEPLETION DURING WET DEPOSITION.)
C
  740 CONTINUE
C
C     SUM CURIES ON THE GROUND OVER ALL STABILITY CLASSES IN
C     EACH SECTOR SEGMENT AND TOTAL CURIES ON THE GROUND.
C
  750 C1=0.0
      C7=0.
      DO 790 MM=1,M
      C2=0.0
      C6=0.
```

```
      DO 760 JJ= 1,J
      IF(WQG(MM,JJ).LE.(1.E-12)) WQG(MM,JJ)=0.
      IF(QG(MM,JJ).LE.(1.E-12)) QG(MM,JJ)=0.0
      C6=C6+WQG(MM,JJ)
  760 C2 = C2 + QG(MM,JJ)
      WQGMI(MM,II)=C6
      QGMI(MM,II) = C2
C
C     COMPUTE SATURATED ACTIVITY ON THE GROUND FOR RELEASE PERIOD OR
C      ONE YEAR ( IN PICOCURIES PER M**2 .
C
      C4=2.6E+06
      C=MONTHS
      IF(C.LE.0.) C=12.
      DECAY=XLMDA(LL)*C*C4
      IF(DECAY.LT.1.E-3) DECAY=1.E-3
      IF(DECAY-5.) 780,780,770
  770 QGAMI(MM,II) = (C2 * 1.0 E+12)/(AREA(MM)*DECAY)
      WQGAMI(MM,II) = (C6 * 1.0 E+12)/(AREA(MM)*DECAY)
  781  ACTDEN(MM,II,LL)=QGAMI(MM,II)+WQGAMI(MM,II)
      GO TO 785
  780 QGAMI(MM,II) =((C2 * 1.0 E+12)/(AREA(MM)*DECAY))*(1.0-EXP(-DECAY))
      WQGAMI(MM,II) =((C6 * 1.0E+12)/(AREA(MM)*DECAY))*(1.0-EXP(-DECAY))
  782 ACTDEN(MM,II,LL)=QGAMI(MM,II)+WQGAMI(MM,II)
  785 C7=C7+C6
  790 C1 = C1 + C2
      C8=C8+C7
      C5 = C5 + C1
      WTQG=C8
  800 TQG = C5
C
C
C      SUM CURIES DEPOSITED WITHIN RADII.
C
      C3=0.
      C4=0.
      DO 810 MM=1,M
      DO 810 II=1,I
      IF(WQGMI(MM,II).LE.(1.E-10)) WQGMI(MM,II)=0.0
      IF(QGMI(MM,II).LE.(1.E-10)) QGMI(MM,II)=0.0
      IF(ACTDEN(MM,II,LL).LE.(1.E-10))ACTDEN(MM,II,LL)=0.0
      C4=C4+QGMI(MM,II)
      C3=C3+WQGMI(MM,II)
      WTQGM(MM) =C3
  810 TQM(MM)=C4
      IF(NCOUNT.NE.0)GO TO 900
C
C     FOR PARTICULATES AND HALOGENS
C     WRITE OUT CURIES PER SQUARE METER ON THE GROUND,
C     SATURATED ACTIVITY PER M**2.
C
  820 WRITE(3,830)(ISO(LL),LATWT(LL))
  830 FORMAT(1H1,20X,'ACTIVITY DENSITY AT END OF RELEASE PERIOD FOR ',
     *            'A UNIFORM RELEASE RATE'/
     *            40X,'PICOCURIES/M**2 OF ',A4,A4)
      WRITE(3,839)
  839 FORMAT(44X,'DRY DEPOSITION'//)
      WRITE(3,840)
  840 FORMAT(47X,7H SECTOR,//1X,9H DISTANCE,/1X,9H (METERS),/16X,2H N
    1,7X,4H NNE,6X,3H NE,6X,4H ENE,8X,2H E,8X,4H ESE,6X,3H SE,6X,4H SSE
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```
      2,4X,12H AREAS(M**2),/95X,19H OF SECTOR-SEGMENTS,/)
       DO 860 MM=1,M
  850 FORMAT(9F10.0,5X,E10.3)
  860 WRITE(3,850) (X(MM),(QGAMI(MM,II),II=1,8),AREA(MM))
      WRITE(3,870)
  870 FORMAT(1HO//17X,
     1          2H S,6X,4H SSW,7X,3H SW,6X,4H WSW,7X,2H W,7X,4H WNW,8X,
     23H NW,6X,4H NNW,6X,17H CURIES DEPOSITED,/97X,13H WITHIN RADII,/)
      DO 880 MM=1,M
  880 WRITE(3,850)(X(MM),(QGAMI(MM,II),II=9,I),TQM(MM))
      QDISP=QL(LL)*TOTFRQ/100.
      WRITE(3,890)(ISO(LL),LATWT(LL),XUP(M),TQG,QDISP)
  890 FORMAT(1HO/
     1       1X,10X,'TOTAL CURIES OF',A4,A4,4X,'DEPOSITED ON THE',
     2          ' GROUND WITHIN',F10.0,' METERS IS',F10.3,' CURIES'/
     3       1X,10X,'OUT OF A TOTAL OF',F10.3,' CURIES DISPERSED',
     4          ' DURING THIS PERIOD.')
C
C            ACCORDING TO ONE REFERENCE (H.P. 18,1,P.74,JAN 70)
C           0.09 CURIE PER LITER APPEARS IN COWS MILK PER CURIE PER
C            SQUARE METER OF I 131 DEPOSITED ON THE GROUND.
C
C      WRITE WET DEPOSITION
C
      IF(RAINF.LE.O..OR.WASHCO.LE.O.) GO TO 900
      WRITE(3,830) (ISO(LL),LATWT(LL))
      WRITE(3,891) (WASHCO,RAINF)
  891 FORMAT(44X,'WET DEPOSITION'//20X,'WASHOUT COEF =',1PE10.2,5X,
     *        'RAINFALL FREQUENCY =',E10.2//)
      WRITE(3,840)
      DO 892 MM=1,M
  892 WRITE(3,850)(X(MM),(WQGAMI(MM,II),II=1,8),AREA(MM))
      WRITE(3,870)
      DO 893 MM=1,M
  893 WRITE(3,850)(X(MM),(WQGAMI(MM,II),II=9,I),WTQGM(MM))
      C=QL(LL)*RAINF*TOTFRQ/100.
      WRITE(3,894)(ISO(LL),LATWT(LL),XUP(M),WTQG,C)
  894 FORMAT(1HO/
     1       1X,10X,'TOTAL CURIES OF',A4,A4,4X,'DEPOSITED ON THE',
     2          ' GROUND WITHIN',F10.0,' METERS IS',F10.3,' CURIES'/
     3       1X,10X,'OUT OF A TOTAL OF',F10.3,' CURIES DISPERSED',
     4          ' DURING RAINFALL.')
  900 CONTINUE
C
C
C      CALCULATE ALL (MXJXIXL) DOSES.
C      SUM DIFFUSED, DECAYED AND DEPLETED DOSES OVER ALL STABILITY CLASSE
C      PRESERVING ISOTOPE DESIGNATION.
C
C     CALCULATE EXTERNAL GAMMA WHOLE BODY DOSES USING THE DOSE INTEGRALS.
C
      DO 1050 LL=1,L
      DO 1050 II=1,I
      DO 1050 MM=1,M
      WIDTH=2.0*PI*X(MM)/I
      C2=0.
      DO 1040 JJ=1,J
      DMIJ=0.
      IF(FREQ(II,JJ).LE.0..OR.UBAR(II,JJ).LE.0.) GO TO 1040
      IF(NDTR(LL).EQ.0.AND.QL(LL).EQ.0.) GO TO 1040
```

```
      IF(NDTR(LL).EQ.1.AND.QL(LL).EQ.0..AND.QL(LL-1).EQ.0.) GO TO 1040
C
C     SINCE CHIOQ INCLUDES DECAY THE DAUGHTER QS'S ARE GROWN BACK TO THE
C      STACK. DAUGHTER INGROWTH IS ADDED TO THE INPUT DAUGHTER STRENGTH.
C
      QS=QL(LL)
      IF(NDTR(LL).NE.0) QS=QS+QL(LL-1)*XLMDA(LL)/(XLMDA(LL)-XLMDA(LL-1))
     1                        *(EXP((XLMDA(LL)-XLMDA(LL-1))*X(MM)
     2                        /UBAR(II,JJ))-1.0)
      IF (LL.GT.NWB.OR.NGAMMA(LL).EQ.0) GO TO 1020
      DECAY=EXP(-XLMDA(LL)*X(MM)/UBAR(II,JJ))
      SIGMA=SIGMZ(JJ,MM)
      IF (SIGMA.GT.SIGZM(2)) GO TO 910
      IS=1
      IF(SIGMA.LT.SIGZM(1)) SIGMA=SIGZM(1)
      GO TO 950
  910 IF (SIGMA.LE.SIGZM(NSIG-1)) GO TO 920
      IS=NSIG-1
      IF(SIGMA.GT.SIGZM(NSIG)) SIGMA=SIGZM(NSIG)
      GO TO 950
  920 IS=8.0*ALOG10(SIGMA)
      DO 930 IN=IS,NSIG
      IF (SIGZM(IN+1).GE.SIGMA) GO TO 940
  930 CONTINUE
  940 IS=IN
  950 PS=(SIGMA-SIGZM(IS))/(SIGZM(IS+1)-SIGZM(IS))
      DISUM=0.
      NGAML=NGAMMA(LL)
      DO 1010 NG=1,NGAML
      EGAM=AGAM(LL,NG)
C     INTERPOLATE DOSE INTEGRAL TABLE TO OBTAIN DI
      IF (EGAM.GT.GAMEN(2)) GO TO 960
      IG=1
      GO TO 1000
  960 IF (EGAM.LE.GAMEN(NGAM-1)) GO TO 970
      IG=NGAM-1
      GO TO 1000
  970 IG=8.0*ALOG10(100.0*EGAM)
      DO 980 IN=IG,NGAM
      IF (GAMEN(IN+1).GE.EGAM) GO TO 990
  980 CONTINUE
  990 IG=IN
 1000 PG=(EGAM-GAMEN(IG))/(GAMEN(IG+1)-GAMEN(IG))
      DI= DOSEI(IG,IS)*(1.0-PG)*(1.0-PS)+DOSEI(IG,IS+1)*(1.0-PG)*PS
     1   +DOSEI(IG+1,IS)*PG*(1.0-PS)+DOSEI(IG+1,IS+1)*PG*PS
 1010 DISUM=DISUM+DI*ABUN(LL,NG)
      DMIJ=DISUM*DECAY*QS*FREQ(II,JJ)*10.0/(WIDTH*UBAR(II,JJ))
      GO TO 1030
 1020 DMIJ=CHIOQ(MM,II,JJ,LL)*QS*DCF(LL)
 1030 DMIJL(MM,II,JJ,LL)=DMIJ
      IF(DMIJ.LE.(1.E-06)) DMIJ=0.
 1040 C2=C2+DMIJ
 1050 DMIL(MM,II,LL)=C2
C
C     FOR ORGANS FOR WHICH THERE IS INPUT DATA:
C
C
C     SUM INDIVIDUAL DOSES IN EACH SECTOR-SEGMENT.
C     CALCULATE       ORGAN MAN-REMS IN EACH SECTOR-SEGMENT,
C     SUM AT RADII  , THEN TOTAL FOR EACH ORGAN.
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C      PRINT MILLIREM           BY SECTOR-SEGMENT,
C      PRINT MAN-REM  BY SECTOR-SEGMENT,
C      PRINT MAN-REM BY RADIUS.
C      WRITE OUT ISOTOPE DATA
C
C
       IF(NWB)1200,1200,1060
 1060  J1=NWB
       C6=0.0
       DO 1090 MM=1,M
       DO 1090 II= 1,I
       C1=0.0
       DO 1070 LL=1,J1
       IF(DMIL(MM,II,LL).LE.(1.E-06)) DMIL(MM,II,LL)=0.
       C1=C1+DMIL(MM,II,LL)
 1070  WBDOS(MM,II)=C1
       IF(NCOUNT.NE.0)GO TO 1081
 1080  DPWB(MM,II)=WBDOS(MM,II)*POP(MM,II)*(0.001)
       GO TO 1082
 1081  DPWB(MM,II)=WBDOS(MM,II)*POPUL(MM,II)*(.001)
 1082  CONTINUE
       C6=C6+DPWB(MM,II)
 1090  DPWBM(MM)=C6
       WRITE(3,1100)
 1100  FORMAT(1H1///25X,82H      DOSE TO AN INDIVIDUAL IN THE INDICATED CO
      1MPASS SECTOR AND ANNULAR RING (MREM)//4X,5H DIST,4X,2H N,
      24X,4H NNE,
      24X,3H NE,3X,4H ENE,4X,2H E,4X,4H ESE,4X,3H SE,3X,4H SSE,4X,2H S,4X
      3,4H SSW,4X,3H SW,3X,4H WSW,4X,2H W,4X,4H WNW,4X,3H NW,3X,4H NNW/)
       DO 1110 MM=1,M
 1110  WRITE(3,1120)(X(MM),(WBDOS(MM,II),II=1,I))
 1120  FORMAT(F9.0,4X,17E7.2)
       WRITE(3,1130)
 1130  FORMAT(1H0//15X,'POPULATION DOSE IN THE INDICATED COMPASS',
      1 ' SECTOR AND ANNULAR RING (MAN-REM)'/31X,'AVERAGED',
      2      ' TO CONFORM TO THE POPULATION WHEEL WIND SECTORS'/41X,
      3 ' FOR THE ESTIMATED POPULATION',//122X,8H RUNNING,/4X,5H DIST,4X,
      4 2H N,4X,4H NNE,
      54X,3H NE,3X,4H ENE,4X,2H E,4X,4H ESE,4X,3H SE,3X,4H SSE,4X,2H S,4X
      6,4H SSW,4X,3H SW,3X,4H WSW,4X,2H W,4X,4H WNW,4X,3H NW,3X,4H NNW,
      7 3X,6H TOTAL)
       DO 1140 MM=1,M
 1140  WRITE(3,1120)(XUP(MM),(DPWB(MM,II),II=1,I),DPWBM(MM))
       WRITE(3,1150)
 1150  FORMAT(1H0/
      1        30X,35H THE CONTRIBUTING RADIONUCLIDES ARE,/)
       WRITE(3,1160)
 1160  FORMAT(10X,8H ISOTOPE,5X,15H CRITICAL ORGAN,6X,4H DCF,6X,16H CURIE
      1S RELEASED,10X,15H DECAY CONSTANT,10X,'DECON FACTOR',/,83X,8H (1/S
      2EC) )
       C2=0.
       DO 1170 LL=1,NWB
       C2=C2+QL(LL)
 1170  WRITE(3,1180)(ISO(LL),LATWT(LL),CRTORG(LL),DCF(LL),QL(LL),XLMDA(LL
      1),DECON(LL))
       WRITE(3,1190) C2
 1180  FORMAT(10X,A4,1X,A4,13X,A4,4X,F10.2,7X,E11.3,15X,E10.2,10X,G10.3)
 1190  FORMAT(48X,'TOTAL CI. ',G11.3)
C
 1200  IF(NTHY)1280,1280,1210
```

```
1210 J2=NWB+1
     C7=0.0
     DO 1240 MM=1,M
     DO 1240 II=1,I
     J3=NWB+NTHY
     C2=0.0
     DO 1220 LL=J2,J3
     IF(DMIL(MM,II,LL).LE.(1.E-06)) DMIL(MM,II,LL)=0.
     C2=C2+DMIL(MM,II,LL)
1220 THYDOS(MM,II)=C2
1230 DPTHY(MM,II)=THYDOS(MM,II)*POP(MM,II)*(0.001)
     C7=C7+DPTHY(MM,II)
1240 DPTHYM(MM)=C7
     WRITE(3,1100)
     DO 1250 MM=1,M
1250 WRITE(3,1120)(X(MM),(THYDOS(MM,II),II=1,I))
     WRITE(3,1130)
     DO 1260 MM=1,M
1260 WRITE(3,1120)(XUP(MM),(DPTHY(MM,II),II=1,I),DPTHYM(MM))
     WRITE(3,1150)
     WRITE(3,1160)
     C2=0.
     DO 1270 LL=J2,J3
     C2=C2+QL(LL)
1270 WRITE(3,1180)(ISO(LL),LATWT(LL),CRTORG(LL),DCF(LL),QL(LL),XLMDA(LL
    1),DECON(LL))
     WRITE(3,1190) C2
1280 IF(NBON)1360,1360,1290
1290 J4=NWB+NTHY+1
     C8=0.0
     DO 1320 MM=1,M
     DO 1320 II=1,I
     J5=NWB+NTHY+NBON
     C3=0.0
     DO 1300 LL=J4,J5
     IF(DMIL(MM,II,LL).LE.(1.E-06)) DMIL(MM,II,LL)=0.
     C3=C3+DMIL(MM,II,LL)
1300 BONDOS(MM,II)=C3
1310 DPBON(MM,II)=BONDOS(MM,II)*POP(MM,II)*(0.001)
     C8=C8+DPBON(MM,II)
1320 DPBONM(MM)=C8
     WRITE(3,1100)
     DO 1330 MM=1,M
1330 WRITE(3,1120)(X(MM),(BONDOS(MM,II),II=1,I))
     WRITE(3,1130)
     DO 1340 MM=1,M
1340 WRITE(3,1120)(XUP(MM),(DPBON(MM,II),II=1,I),DPBONM(MM))
     WRITE(3,1150)
     WRITE(3,1160)
     C2=0.
     DO 1350 LL=J4,J5
     C2=C2+QL(LL)
1350 WRITE(3,1180)(ISO(LL),LATWT(LL),CRTORG(LL),DCF(LL),QL(LL),XLMDA(LL
    1),DECON(LL))
     WRITE(3,1190) C2
1360 IF(NSKN) 1440,1440,1370
1370 J6=NWB+NTHY+NBON+1
     C9=0.0
     DO 1400 MM=1,M
     DO 1400 II=1,I
```

```
      J7=NWB+NTHY+NBON+NSKN
      C4=0.0
      DO 1380 LL=J6,J7
      IF(DMIL(MM,II,LL).LE.(1.E-06)) DMIL(MM,II,LL)=0.
      C4=C4+DMIL(MM,II,LL)
 1380 SKNDOS(MM,II)=C4
 1390 DPSKN(MM,II)=SKNDOS(MM,II)*POP(MM,II)*(0.001)
      C9=C9+DPSKN(MM,II)
 1400 DPSKNM(MM)=C9
      WRITE(3,1100)
      DO 1410 MM=1,M
 1410 WRITE(3,1120)(X(MM),(SKNDOS(MM,II),II=1,I))
      WRITE(3,1130)
      DO 1420 MM=1,M
 1420 WRITE(3,1120)(XUP(MM),(DPSKN(MM,II),II=1,I),DPSKNM(MM))
      WRITE(3,1150)
      WRITE(3,1160)
      C2=0.
      DO 1430 LL=J6,J7
      C2=C2+QL(LL)
 1430 WRITE(3,1180)(ISO(LL),LATWT(LL),CRTORG(LL),DCF(LL),QL(LL),XLMDA(LL
     1),DECON(LL))
      WRITE (3,1190) C2
 1440 CONTINUE
C     A PATCH TO WRITE INDIVIDUAL DOSES MAY BE INSERTED HERE
      C1 = 0.0
      DO 1450 MM=1,M
      DO 1450 II=1,I
      C1 = C1 + POP(MM,II)
 1450 TOTPOP=C1
      C1 = 0.0
      WRITE(3,1460) FACIL,MONTH1,NYR1,
     *               MONTH2,NYR2,ETHERM,MONTHS,TOTFRQ,TOTPOP,HOLDUP,H
 1460 FORMAT(1H1/46X,'PROBLEM SUMMARY'//6X,'FACILITY',14X,'PERIOD',
     *       11X,'ENERGY',4X,'MONTHS OF',2X,'TOTAL',6X,'TOTAL',7X,
     *       'HOLDUP',2X,'HEFF'/24X,'FROM',7X,'TO',6X,'(MW-D(TH))',
     *       2X,'OPERATION',2X,'FREQUENCY',2X,'POPULATION',2X,'(DAYS)',
     *       2X,'(METERS)'/
     *       1X,5A4,2(1X,A4,I5),F11.0,1X,F5.2,6X,F8.1,3X,F11.0,1X,F6.1,
     *       2X,F7.0)
      WRITE(3,1520)
 1520 FORMAT(1H0,61H RADIONUCLIDE CONTRIBUTIONS TO THE TOTAL POPULATION
     1 DOSE ARE,/)
      IF(NCOUNT.NE.0)GO TO 1541
      DO 1543 LL=1,L
      DPL=0.
      DO 1530 II=1,I
      DO 1530 MM=1,M
 1530 DPL=DPL+DMIL(MM,II,LL)*POP(MM,II)*(0.001)
      IF(DPL.LE.1.E-06)DPL=0.0
      WRITE(3,1540)ISO(LL),LATWT(LL),DPL
 1540 FORMAT(1X,A4,1X,A4,14X,E10.5,8H MAN REM)
 1543 CONTINUE
      GO TO 1550
 1541 DO 1549 LL=1,L
      DPL=0.
      DO 1542 II=1,I
      DO 1542 MM=1,M
 1542 DPL=DPL+DMIL(MM,II,LL)*POPUL(MM,II)*(.001)
      WRITE(3,1540)ISO(LL),LATWT(LL),DPL
```

```
 1549 CONTINUE
 1550 CONTINUE
C      COMPUTE TOTAL DOSE PER SECTOR
       WRITE(3,3210)
 3210 FORMAT('1'////40X,'TOTAL INTEGRATED DOSE DUE TO GROUND ',
     1'DEPOSITION'//)
      DO 2001 LL=1,L
      READ(1,2005)DOSFAC,XLAMBD(LL),TIME,NORGAN
 2005  FORMAT(F10.4,E15.3,F5.1,I5)
      DO 3220 MM=1,M
      DO 3230 II=1,I
      DR(MM,II)=ACTDEN(MM,II,LL)*(1.0E-12)*DOSFAC*24.
      TD(MM,II)=(DR(MM,II)/XLAMBD(LL)*(1.-EXP(-XLAMBD(LL)*TIME)))*1000.
      IF(DR(MM,II).LE.1.E-15)DR(MM,II)=0.
      IF(TD(MM,II).LE.1.E-15)TD(MM,II)=0.
 3230 CONTINUE
 3220 CONTINUE
      WRITE(3,2030)(ISO(LL),LATWT(LL),TIME)
 2030 FORMAT(' ',14X,'TOTAL INTEGRATED DOSE TO AN INDIVIDUAL(MREM) ',
     *'DUE TO GROUND',
     1' DEPOSITION OF RADIONUCLIDE  ',A4,A4/
     250X,'TOTAL TIME IN DAYS=  ',F5.1/)
      IF(NORGAN.EQ.1)GO TO 2033
 2031 WRITE(3,2032)
 2032 FORMAT(42X,'THIS CALCULATION APPLIES FOR WHOLE BODY DOSES'//)
      GO TO 3200
 2033 WRITE(3,2034)
 2034 FORMAT(52X,'SKIN DOSE RECEIVED')
 3200 WRITE(3,840)
      DO 2000 MM=1,M
      WRITE(3,6700)(X(MM),(TD(MM,II),II=1,8),AREA(MM))
 6700 FORMAT(F10.0,2X,8F10.3,5X,E10.3)
 2000 CONTINUE
 3300 FORMAT(1H0//17X,2H S,6X,4H SSW,7X,3H SW,6X,4H WSW,7X,
     12H W,7X,4H WNW,8X,3H NW,6X,4H NNW,6X,/)
      WRITE(3,3300)
      DO 3310 MM=1,M
 3310 WRITE(3,6700)(X(MM),(TD(MM,II),II=9,I))
      IF(NORGAN.EQ.1)GO TO 2001
C       COMPUTE THE MAN-REM TOTAL FOR WHOLE BODY CALCULATIONS
      XMNREM=0.
      XMANRM=0.
      DO 2050 MM=1,M
      DO 2050 II=1,I
      IF(NCOUNT.GT.0)GO TO 4001
      XMNREM=POP(MM,II)*TD(MM,II)*.001
      IF(XMNREM.LE.1.E-10)XMNREM=0.
      XMANRM=XMNREM+XMANRM
      GO TO 2050
 4001 DO 4002 MM=1,M
      DO 4002 II=1,I
 4002 FX2(MM,II)=AP+(1.-AP)*EXP(-XLAM*TIME-TLAG+TAWL)
      IF(FX2(MM,II).LE.1.E-06)FX2(MM,II)=0.
      DO 4003 MM=1,M
      DO 4003 II=1,I
 4003 POP2(MM,II)=POP(MM,II)*FX2(MM,II)
      IF(POP2(MM,II).LE..9)POP2(MM,II)=0.
      DO 4004 MM=1,M
      DO 4004 II=1,I
      XMNREM=POP2(MM,II)*TD(MM,II)*.001+((POPUL(MM,II)-POP2(MM,II))
```

```
     * /2.)*TD(MM,II)*.001
       IF(XMNREM.LE.1.E-10)XMNREM=0.
       XMANRM=XMNREM+XMANRM
 4004  CONTINUE
 2050  CONTINUE
       WRITE(3,2060)(XMANRM)
 2060  FORMAT(' '//40X,'TOTAL MANREM FOR THIS NUCLIDE= ',F15.6//)
 2001  CONTINUE
       IF(NCOUNT.GT.0)GO TO 3050
       READ(1,2073)(AP,XLAM,TLAG,TAWL,NEVAC)
       IF(NEVAC)2071,3050,2140
 2071  CONTINUE
 2073  FORMAT(4F10.2,I5)
       WRITE(3,3060)
 3060  FORMAT('1'///55X,'EVACUATION MODEL'///
      141X,'POPULATION MOVED BEYOND FURTHEST RADIUS SHOWN'//)
       WRITE(3,2072)(AP,XLAM,TLAG,TAWL)
 2072  FORMAT(' ',20X,'FRACTION OF POPULATION UNAFFECTED BY',
      11X,'EVACUATION= ',F10.2/
      220X,'EVACUATION RATE= ',F10.2/
      320X,'TIME LAG TO EVACUATION NOTICE= ',F10.2/
      420X,'TIME BETWEEN IMPENDING CORE MELT AND LEAKAGE= ',F10.2//)
       WRITE(3,2112)
 2112  FORMAT(' ','CLOUD VELOCITIES(M/SEC)')
       DO 2080 II=1,I
       CLDVEL=0.
       DO 2070 JJ=1,J
       CLDV=UBAR(II,JJ)*FREQ(II,JJ)
 2070  CLDVEL=CLDV+CLDVEL
       CLDVEL=CLDVEL/100.
       WRITE(3,2104)CLDVEL
 2104  FORMAT(' ',E15.7)
       DO 2077 MM=1,M
       IF(CLDVEL.LE.1.0E-05)GO TO 2076
 2075  CLDTIM(MM,II)=X(MM)/CLDVEL
       GO TO 2077
 2076  CLDTIM(MM,II)=1.E 10
 2077  CONTINUE
 2080  CONTINUE
       WRITE(3,2113)
 2113  FORMAT(' ','CLOUD TRAVEL TIME(SEC)')
       DO 2106 MM=1,M
 2106  WRITE(3,2105)(CLDTIM(MM,II),II=1,I)
 2105  FORMAT(' ',16E7.2)
       DO 2090 MM=1,M
       DO 2100 II=1,I
       FX(MM,II)=AP+(1.-AP)*EXP(-XLAM*((CLDTIM(MM,II)/(3600.*24.))
      1-TLAG+TAWL))
 2100  IF(FX(MM,II).LE.1.E-06)FX(MM,II)=0.
 2090  CONTINUE
       WRITE(3,2114)
 2114  FORMAT(' ','POPULATION FRACTION REMAINING')
       DO 2102 MM=1,M
 2102  WRITE(3,2101)(FX(MM,II),II=1,I)
 2101  FORMAT(' ',16E8.2)
       DO 3330 MM=1,M
       DO 3320 II=1,I
 3320  POPUL(MM,II)=POP(MM,II)*FX(MM,II)
       IF(POPUL(MM,II).LE.0.9)POPUL(MM,II)=0.
 3330  CONTINUE
```

```
      NCOUNT=NCOUNT+1
      GO TO 133
 2140 CONTINUE
      WRITE(3,3070)
 3070 FORMAT('0',55X,'EVACUATION MODEL'/
     12X,'POPULATION MOVED TO A DISTANCE MIDWAY BETWEEN THE',
     2' RELEASE POINT AND THE OUTERMOST RADIUS',
     3' IN A DIRECTION AWAY FROM THE CLOUD'/
     438X,'THE POPULATION OUTSIDE THE MIDPOINT IS NOT MOVED'//)
      WRITE(3,2072)(AP,XLAM,TLAG,TAWL)
      M=M/2
      DO 3000 II=1,I
      CLDVEL=0.
      DO 3010 JJ=1,J
      CLDV=UBAR(II,JJ)*FREQ(II,JJ)
 3010 CLDVEL=CLDV+CLDVEL
      CLDVEL=CLDVEL/100.
      DO 3000 MM=1,M
      IF(CLDVEL.LE.1.0E-05)GO TO 5000
 3020 CLDTIM(MM,II)=X(MM)/CLDVEL
      GO TO 3000
 5000 CLDTIM(MM,II)=1.0E 05
 3000 CONTINUE
      DO 3030 MM=1,M
      DO 3030 II=1,I
 3040 FX(MM,II)=AP+(1.-AP)*EXP(-XLAM*((CLDTIM(MM,II)/(3600.*24.))
     1-TLAG+TAWL))
      IF(FX(MM,II).LE.1.E-06)FX(MM,II)=0.
 3030 CONTINUE
      DO 3190 MM=1,M
      DO 3190 II=1,I
 3180 POPUL(MM,II)=POP(MM,II)*FX(MM,II)
      IF(POPUL(MM,II).LE.0.9)POPUL(MM,II)=0.
 3190 CONTINUE
      MMM=M+1
      M=2*M
      DO 8000 MM=MMM,M
      DO 8000 II=1,I
 8000 POPUL(MM,II)=POP(MM,II)
      NCOUNT=NCOUNT+1
      GO TO 133
 3050 CONTINUE
 1551 CALL EXIT
      STOP
      END
      FUNCTION SIGZ(KLASS,X)
C     FUNCTIONS ARE OAP/EPA FITS TO SIGMA ZEES
C     IN EPA OFFICE OF AIR PROGRAMS DOCUMENT  NO.AP-26.(USGPO,WASH.,DC.
C     STOCK NO.5503-0015. PRICE ONE DOLLAR.)
C     FUNCTION CALCULATES THE STANDARD DEVIATION OF PLUME CONCENTRATION
C          IN THE Z DIRECTION FOR STABILITY KLASS (1 = A, 2 = B, 3 = C,
C          4 = D, 5 = E, 6 = F) AND THE DISTANCE ALONG THE CENTERLINE OF
C          THE PLUME IN KILOMETERS, X.
C     THE STANDARD DEVIATION IS IN METERS.
C     AS WRITTEN, A CAPPING LAYER (SIGMAX)   UPPER BOUNDS SIGZ
C
C     THE RUN IS STOPPED IF X(MM) IS LESS THAN 100. METERS
C
  100 IF (X - 0.1) 110,130,130
  110 WRITE(3,120)
```

```
120 FORMAT(1X,'ONE X IS TOO SMALL. CHECK X, XUP,AND XLOW DATA.')
    STOP
130 XX = ALOG(X)
    SIGMAX=10000.
    GO TO (140,170,180,190,200,210), KLASS
140 IF(X-1.5) 150,150,160
150 SIGZ = EXP(6.126788 + XX * (2.214445 + XX * (-0.041129 + XX *
   1(-0.379863 + XX* (-0.099597)))))
    IF (SIGZ-SIGMAX) 220,220,230
160 SIGZ=500. * X**2
    IF (SIGZ-SIGMAX) 220,220,230
170 SIGZ = EXP(4.686302 + XX * (1.062550 + XX * (0.018771)))
    IF (SIGZ-SIGMAX) 220,220,230
180 SIGZ = 61.141032 * X ** .914651
    IF (SIGZ-SIGMAX) 220,220,230
190 SIGZ = EXP(3.416367 + XX * (0.729577 + XX * (-0.031207)))
    IF (SIGZ-SIGMAX) 220,220,230
200 SIGZ = EXP(3.057629 + XX * (0.679089 + XX * (-0.044892)))
    IF (SIGZ-SIGMAX) 220,220,230
210 SIGZ = EXP(2.625488 + XX * (0.658866 + XX * (-0.054137)))
    IF (SIGZ-SIGMAX) 220,220,230
230 SIGZ = SIGMAX
220 RETURN
    END
```

```
      SUBROUTINE RIVCON(ISO,XLAMBD,ACTDEN,CRTORG,LATWT,L,M,I)
      INTEGER RADIUS(20),SECTOR(20)
      DIMENSION CCONC(20,20)
      DIMENSION AVCROS(20),AAVCRS(20)
      DIMENSION SOLUB(20),FRACT(20),TWIDTH(20,20),TOTFIN(20)
      DIMENSION TVLTIM(20),QREACH(20,20),CROSS(20,20),QQAVE(20),
     1SURFA(20),PLTDEN(20),XLRCH(20),ISO(20),XLAMBD(20)
     2,XDEPTH(20,20,20),QAVE(20),C(20),CCI(20),CRTORG(20),LATWT(20),
     3 FINAL(20,20),NUMB(20)
```

```
      DIMENSION ACTDEN(12,16,20)
      COMMON/ONE/ACT(12,16,20),XXTIM,CONCEN(20,20)
      COMMON/TWO/RADIUS,SECTOR,IIRECH
      INTEGER WATFAC(20)
      DO 910 MM=1,M
      DO 910 II=1,I
      DO 910 LL=1,L
  910 ACT(MM,II,LL)=ACTDEN(MM,II,LL)
      READ(1,10)XXTIM
      IF(XXTIM.EQ.0.)GO TO 611
      WRITE(3,660)
  660 FORMAT('1',32X,'THE FOLLOWING SECTION COMPUTES THE ',
     1 'CONCENTRATIONS OF VARIOUS NUCLIDES'/40X,'IN A RIVER WITHIN ',
     2 'THE AREA OF INTEREST OF THIS STUDY'/47X,
     3 'DUE TO DEPOSITION ON THE RIVER SURFACE'/)
   10 FORMAT(F10.0)
      WRITE(3,20)XXTIM
   20 FORMAT('0',18X,'THE DELAY TIME IN DAYS BEFORE COMPUTING THE WATER
     1CONCENTRATIONS IS ',F10.0//)
      READ(1,30)TIMOUT,TIMIN,OUTVEL,XINVEL,NINOUT,IIRECH,NDEPTH,NPROF
   30 FORMAT(4F5.1,4I5)
      WRITE(3,40)TIMOUT,TIMIN,OUTVEL,XINVEL,NINOUT,IIRECH,NDEPTH,NPROF
      IIRECH=IIRECH+1
   40 FORMAT(' ',20X,'THE TIME(HRS) THAT THE TIDE FLOWS OUT= ',T85,F5.1/
     120X,'THE TIME(HRS) THAT THE TIDE FLOWS IN= ',T85,F5.1/
     220X,'THE WATER VELOCITY(AVG) WHEN THE TIDE GOES OUT= ',T85,F5.1/
     320X,'THE WATER VELOCITY(AVG) WHEN THE TIDE COMES IN= ',T85,F5.1/
     420X,'THE TIDE INITIALLY FLOWS IN DIRECTION ',T85,I5,'(0=OUT,',
     5'1=IN)'/20X,'THE NUMBER OF REACHES= ',T85,I5/
     620X,'THE NUMBER OF DEPTHS/CROSS SECTIONAL PROFILE= ',T85,I5/
     720X,'THE NUMBER OF PROFILES/REACH= ',T85,I5//)
      DO 700 LL=1,L
  700 READ(1,60)PLTDEN(LL),SOLUB(LL),FRACT(LL)
      DO 710 IREACH=2,IIRECH
  710 READ(1,90) XLRCH(IREACH),SURFA(IREACH),WATFAC(IREACH)
      DO 720 IREACH=2,IIRECH
      DO 720 NNPROF=1,NPROF
  720 READ(1,230)(TWIDTH(IREACH,NNPROF),(XDEPTH(IREACH,NNPROF,NDEP),
     1NDEP=1,NDEPTH))
      DO 590 LL=1,L
      WRITE(3,900)ISO(LL),LATWT(LL)
      EXCESS=0.
      WRITE(3,70)PLTDEN(LL),SOLUB(LL),FRACT(LL)
      DO 590 IREACH=2,IIRECH
      C(IREACH)=0.
      CCI(IREACH)=0.
      CONCEN(1,LL)=0.
      IF(LL.GT.1)GO TO 750
      READ(1,340)NUMB(IREACH),RADIUS(IREACH),SECTOR(IREACH)
  750 CONTINUE
      WRITE(3,901)NUMB(IREACH)
      WRITE(3,100)XLRCH(IREACH),SURFA(IREACH),WATFAC(IREACH)
      DISTAN=0.
      TVLTIM(1)=0.
      DISNEW=0.
      DISTNW=0.
      IF(NINOUT.LE.0.AND.IREACH.EQ.2)GO TO 110
C
C  COMPUTE THE TVLTIME, THE TIME IT TAKES FOR THE AVERAGE PACKET OF WAT
C   ER TO TRAVEL THE FULL LENGTH OF THE REACH
```

```
C
C     FOR THE TIDE COMING IN:
C
      DISTT=XINVEL*TIMIN
      TVLTIM(IREACH)=TIMIN+EXCESS
      DISTAN=OUTVEL*TIMOUT-DISTT+OUTVEL*EXCESS
      IF(DISTAN.LE.1.E-10)DISTAN=0.
      IF(XLRCH(IREACH)-DISTAN)1201,1110,1200
 1200 TVLTIM(IREACH)=TVLTIM(IREACH)+TIMOUT
      GO TO 130
C     FOR THE TIDE INITIALLY GOING OUT:
  110 DISTAN=OUTVEL*TIMOUT
      IF(DISTAN.LE.1.E-10)DISTAN=0.
      IF(XLRCH(IREACH)-DISTAN)210,200,120
  120 TVLTIM(IREACH)=TIMOUT
  130 DISTNW=DISTAN-XINVEL*TIMIN
      IF(DISTNW.LE.1.E-10)DISTNW=0.
      TVLTIM(IREACH)=TVLTIM(IREACH)+TIMIN
      DISNEW=DISTNW+OUTVEL*TIMOUT
      IF(XLRCH(IREACH)-DISNEW)160,150,140
  140 TVLTIM(IREACH)=TVLTIM(IREACH)+TIMOUT
      GO TO 130
  150 TVLTIM(IREACH)=TVLTIM(IREACH)+TIMOUT
      GO TO 170
  160 DISTAN=DISNEW-XLRCH(IREACH)
      IF(DISTAN.LE.1.E-10)DISTAN=0.
      EXCESS=DISTAN/OUTVEL
      IF(EXCESS.LE.1.E-20)EXCESS=0.
      TVLTIM(IREACH)=TVLTIM(IREACH)-EXCESS+OUTVEL*TIMOUT
      IF(TVLTIM(IREACH).LE.1.E-15)TVLTIM(IREACH)=0.
      GO TO 170
 1110 TVLTIM(IREACH)=TVLTIM(IREACH)+TIMOUT
      EXCESS=0.
      GO TO 170
 1201 TVLTIM(IREACH)=TVLTIM(IREACH)+TIMOUT
      DIS=DISTAN-XLRCH(IREACH)
      EXCESS=DIS/OUTVEL
      TVLTIM(IREACH)=TVLTIM(IREACH)-EXCESS
  170 CONTINUE
      GO TO 220
  200 TVLTIM(IREACH)=TIMOUT
      GO TO 170
  210 DISTAN=XLRCH(IREACH)
      TVLTIM(IREACH)=DISTAN/OUTVEL
      IF(TVLTIM(IREACH).LE.1.E-15)TVLTIM(IREACH)=0.
      GO TO 170
  220 CONTINUE
      DO 320 NNPROF=1,NPROF
C
C   DETERMINE THE VERTICAL CROSS SECTIONAL AREA(IN SQ METERS) OF THE
C   REACH(CROSS(IREACH))USING SIMPSON'S RULE
C
C   USE AN ODD NUMBER OF DEPTHS TO DIVIDE THE WIDTH INTO 2M EQUAL
C                                                          SUBINTERVALS
C
      DEPTH=NDEPTH
      DELTAX=TWIDTH(IREACH,NNPROF)/(DEPTH-1.)
      NDEP=1
      IF(NDEPTH.EQ.3)GO TO 260
      IF(NDEPTH.EQ.5)GO TO 270
```

```
      IF(NDEPTH.EQ.7)GO TO 280
      IF(NDEPTH.EQ.9)GO TO 290
      IF(NDEPTH.EQ.11)GO TO 300
      IF(NDEPTH.GT.11)GO TO 240
      IF(NDEPTH.LE.2)GO TO 240
  240 WRITE(3,250)
  260 CROSS(IREACH,NNPROF)=((DELTAX/3.)*(XDEPTH(IREACH,NNPROF,NDEP)
     1+4.*XDEPTH(IREACH,NNPROF,NDEP+1)+XDEPTH(IREACH,NNPROF,NDEP+2)))*
     2.0929
      GO TO 310
  270 CROSS(IREACH,NNPROF)=((DELTAX/3.)*(XDEPTH(IREACH,NNPROF,NDEP)
     1+4.*XDEPTH(IREACH,NNPROF,NDEP+1)+2.*XDEPTH(IREACH,NNPROF,NDEP+2)
     2+4.*XDEPTH(IREACH,NNPROF,NDEP+3)+XDEPTH(IREACH,NNPROF,NDEP+4)))*
     3 .0929
      GO TO 310
  280 CROSS(IREACH,NNPROF)=((DELTAX/3.)*(XDEPTH(IREACH,NNPROF,NDEP)
     1+4.*XDEPTH(IREACH,NNPROF,NDEP+1)+2.*XDEPTH(IREACH,NNPROF,NDEP+2)
     2 +4.*XDEPTH(IREACH,NNPROF,NDEP+3)+2.*XDEPTH(IREACH,NNPROF,NDEP+4)
     3 +4.*XDEPTH(IREACH,NNPROF,NDEP+5)+XDEPTH(IREACH,NNPROF,NDEP+6)))*
     4 .0929
      GO TO 310
  290 CROSS(IREACH,NNPROF)=((DELTAX/3.)*(XDEPTH(IREACH,NNPROF,NDEP)
     1 +4.*XDEPTH(IREACH,NNPROF,NDEP+1)+2.*XDEPTH(IREACH,NNPROF,NDEP+2)
     2+4.*XDEPTH(IREACH,NNPROF,NDEP+3)+2.*XDEPTH(IREACH,NNPROF,NDEP+4)
     3+4.*XDEPTH
     3 (IREACH,NNPROF,NDEP+5)+2.*XDEPTH(IREACH,NNPROF,NDEP+6)+4.*
     4 XDEPTH(IREACH,NNPROF,NDEP+7)+XDEPTH(IREACH,NNPROF,NDEP+8)))*.0929
      GO TO 310
  300 CROSS(IREACH,NNPROF)=((DELTAX/3.)*(XDEPTH(IREACH,NNPROF,NDEP)
     1 +4.*XDEPTH(IREACH,NNPROF,NDEP+1)+2.*XDEPTH(IREACH,NNPROF,NDEP+2)
     2 +4.*XDEPTH(IREACH,NNPROF,NDEP+3)+2.*XDEPTH(IREACH,NNPROF,NDEP+4)
     3 +4.*XDEPTH(IREACH,NNPROF,NDEP+5)+2.*XDEPTH(IREACH,NNPROF,NDEP+6)
     4 +4.*XDEPTH(IREACH,NNPROF,NDEP+7)+2.*XDEPTH(IREACH,NNPROF,NDEP+8)
     5 +4.*XDEPTH(IREACH,NNPROF,NDEP+9)+XDEPTH(IREACH,NNPROF,NDEP+10)))
     6 *.0929
  310 QREACH(IREACH,NNPROF)=(9.99997E 02)*(ABS(OUTVEL-XINVEL)*
     14.470193E-01)*(CROSS(IREACH,NNPROF))
  320 CONTINUE
      QAVE(IREACH)=0.
      DO 330 NNPROF=1,NPROF
  330 QAVE(IREACH)=QREACH(IREACH,NNPROF)+QAVE(IREACH)
      Z=NPROF
      QQAVE(IREACH)=QAVE(IREACH)/Z
C
C     COMPUTE NUCLIDE CONCENTRATION
C
      AVCROS(IREACH)=0.
      AAVCRS(1)=1.
      SURFA(1)=0.
      XLRCH(1)=1.
      TVLTIM(1)=0.
      CONCEN(1,LL)=0.
      QQAVE(1)=0.
      DO 350 NNPROF=1,NPROF
  350 AVCROS(IREACH)=CROSS(IREACH,NNPROF)+AVCROS(IREACH)
      CC=NPROF
      AAVCRS(IREACH)=AVCROS(IREACH)/CC
      MM=RADIUS(IREACH)
      II=SECTOR(IREACH)
      IF(NUMB(IREACH).EQ.1)ACTDEN(MM,II,LL)=0.
```

```
      CONCEN(IREACH,LL)=(ACTDEN(MM,II,LL)*SURFA(IREACH-1)*.0929)
     1/(AAVCRS(IREACH-1)*XLRCH(IREACH-1)*5280.*2.8317E-02*9.9997E 02)
  451 IF(NUMB(IREACH).GT.20)GO TO 452
      GO TO 470
  452 WRITE(3,460)
      GO TO 610
C
C  THE FIRST TERM C IS THE CONCENTRATION DUE TO THE CONTRIBUTION OF
C  THE PREVIOUS REACH
C
  470 C(IREACH)=(QQAVE(IREACH-1)*CONCEN(IREACH-1,LL)*EXP((-XLAMBD(LL)
     1/24.)*TVLTIM(IREACH-1)))*EXP(-XLAMBD(LL)*XXTIM)
      XLL=XLRCH(IREACH-1)
      AAX=AAVCRS(IREACH-1)
      SXX=SURFA(IREACH-1)
      TVX=TVLTIM(IREACH-1)
      QX=QQAVE(IREACH-1)
C
C   THE SECOND TERM CCI IS THE CONCENTRATION DUE TO THE CONTRIBUTION
C   OF DIRECT DEPOSITION AND THE PLANT DISCHARGE
C
      CCI(IREACH)=((ACTDEN(MM,II,LL)*EXP(-XLAMBD(LL)*XXTIM)*SURFA(IREACH
     1 )*.0929)/(AAVCRS(IREACH)*XLRCH(IREACH)*5280.*.3048*9.99972E 02))+
     2 PLTDEN(LL)
      CCONC(IREACH,LL)=(C(IREACH)+CCI(IREACH))*(1./QQAVE
     1(IREACH))
      WRITE(3,480)ISO(LL),LATWT(LL),NUMB(IREACH),CCONC(IREACH,LL)
C
C   THE FOLLOWING DETERMINES THE DRINKING WATER CONCENTRATION FOR
C   THE VARIOUS WATER TREATMENT FACILITIES AVAILABLE
      IF(WATFAC(IREACH).EQ.1)GO TO 500
      IF(WATFAC(IREACH).EQ.2)GO TO 530
      IF(WATFAC(IREACH).GT.2)GO TO 540
      WRITE(3,490)
  500 FINAL(IREACH,LL)=CCONC(IREACH,LL)
      IF(WATFAC(IREACH).EQ.1)GO TO 501
      GO TO 590
  501 WRITE(3,510)FINAL(IREACH,LL)
      GO TO 590
  530 FINAL(IREACH,LL)=CCONC(IREACH,LL)*SOLUB(LL)
      WRITE(3,550)FINAL(IREACH,LL)
      GO TO 590
  540 FINAL(IREACH,LL)=FRACT(LL)*CCONC(IREACH,LL)*SOLUB(LL)
      IF(WATFAC(IREACH).EQ.4)GO TO 570
      WRITE(3,560)FINAL(IREACH,LL)
      GO TO 590
  570 WRITE(3,580)FINAL(IREACH,LL)
  590 CONTINUE
   60 FORMAT(E15.6,F10.2,F10.2)
   70 FORMAT('0',20X,'PLANT DISCHARGE OF THIS NUCLIDE IN PCI/SEC= ',
     1T120,E10.2/10X,'THE SOLUBILITY OF THIS NUCLIDE IN COLD WATER= ',
     2 T120,F10.2/20X,'THE DISSOLVED NUCLIDE FRACTION PASSING ',
     3 'WATER TREATMENT FACILITIES OF ALL TYPES IS ',T120,F10.2//)
   90 FORMAT(F10.3,E15.6,I5)
  100 FORMAT(' ',20X,'THE LENGTH OF THE REACH IN MILES= ',T70,
     1 F10.3/20X,'THE SURFACE AREA OF THE RIVER IN THIS REACH= ',T70,
     2 E15.3/20X,'THE WATER TREATMENT FACILITY CLASS TYPE= ',T70,I5/ )
  230 FORMAT(12F6.1)
  250 FORMAT('0',2X,'ERROR...THE NUMBER OF DEPTHS IS NOT ALLOWED')
  340 FORMAT(3I5)
```

```
460 FORMAT('0',10X,'ERROR...NUMBER OF REACHES EXCEEDS 20'///)
480 FORMAT('-',11X,'THE AVERAGE CONCENTRATION OF ',A4,A4,2X,
   1' IN REACH ',I5,' IS ',E16.7,' PCI/L'/
   141X,'BEFORE WATER TREATMENT'///)
490 FORMAT(' ',37X,'THERE ARE NO WATER TREATMENT FACILITIES IN THIS',
   1' REACH '///)
510 FORMAT('0',10X,'THERE IS A CLASS 1 WATER TREATMENT FACILITY IN ',
   1'THIS REACH WHICH PROVIDES:'/10X,'NO TREATMENT OTHER THAN ',
   2'CHLORINATION'/10X,'THERE IS NO REDUCTION IN DISSOLVED OR ',
   3'SUSPENDED RADIONUCLIDES'/10X,'THE CONCENTRATION AFTER WATER ',
   4'TREATMENT THEREFORE IS ',E16.7,'PCI/L'//)
550 FORMAT('0',10X,'THERE IS A CLASS 2 WATER TREATMENT FACILITY IN ',
   1'THIS REACH WHICH PROVIDES:'/10X,'FILTRATION AND CHLORINATION.  ',
   2' ALL SUSPENDED RADIONUCLIDES ARE REMOVED BUT NO DISSOLVED ',
   3'RADIONUCLIDES'/10X,'THE CONCENTRATION AFTER WATER TREATMENT ',
   4'IS',E16.7,'PCI/L'//)
560 FORMAT('0',10X,'THERE IS A CLASS 3 WATER TREATMENT FACILITY IN ',
   1'THIS REACH WHICH PROVIDES:'/10X,'CHEMICAL PROCESSING.  ',
   2'VARIABLE AMOUNTS OF DISSOLVED AND NEARLY ALL SUSPENDED ',
   3'RADIONUCLIDES'/10X,'THE CONCENTRATION AFTER WATER TREATMENT IS ',
   4E16.7,'PCI/L'//)
580 FORMAT('0',10X,'THERE IS A CLASS 4 WATER TREATMENT FACILITY IN ',
   1'THIS REACH WHICH PROVIDES:'/10X,'FILTRATION PLUS CHEMICAL ',
   2'PROCESSING.  ALL SUSPENDED AND VARIABLE AMOUNTS OF DISSOLVED ',
   3'RADIONUCLIDES ARE REMOVED'/10X,'THE CONCENTRATION AFTER  ',
   4'WATER TREATMENT IS ',E16.7,'PCI/L'//)
900 FORMAT('0',64X,A4,A4/)
901 FORMAT('0',64X,'REACH',2X,I5)
    WRITE(3,630)
    DO 610 IREACH=2,IIRECH
    TOTFIN(IREACH)=0.
    DO 600 LL=1,L
600 TOTFIN(IREACH)=FINAL(IREACH,LL)+TOTFIN(IREACH)
    WRITE(3,620)NUMB(IREACH),TOTFIN(IREACH)
620 FORMAT(' ',20X,'THE TOTAL DRINKING WATER CONCENTRATION IN REACH ',
   1I5,2X,' IS ',E16.4,' PCI/L'/)
630 FORMAT('1'//47X,'SUMMARY OF RADIONUCLIDE CONCENTRATIONS'/)
610 CONTINUE
    CALL FISHR(CCONC,RADIUS,SECTOR,ISO,LATWT,L,IIRECH,NUMB)
611 CALL LAKEDS(ACTDEN,L,M,I,LATWT,ISO,SCLUB,FRACT,XLAMBD)
    RETURN
    END
```

```
 SUBROUTINE LAKEDS(ACT,L,M,I,LATWT,ISC,SOLUB,FRACT,
1XLAMBD)
 DIMENSION SWIMDF(20),BOATDF(20),SKINDF(20),ACT(12,16,20),
1DOSSWB(20),DOSBWB(20),DOSSSK(20),ISO(20),LATWT(20),CON(20),
2 FINAL(20),SOLUB(20),FRACT(20)
 DIMENSION BOATSK(20),DOSBSK(20),XLAMBD(20)
 INTEGER SETUP,DESDOS
 INTEGER WATFAC
 READ(1,10)SETUP
```

```
   10 FORMAT(I5)
      DO 482 JJJ=1,SETUP
      IF(SETUP.EQ.0)GO TO 481
      READ(1,20)SURF,SWIM,BOAT,VOLUME
      WRITE(3,11)SURF,SWIM,BOAT,VOLUME
   11 FORMAT('0'//20X,'LAKE SURFACE AREA(SQ FT)= ',T50,E15.2/
     1 20X,'TIME(HRS) SPENT SWIMMING= ',T50,F10.1/
     2 20X,'TIME(HRS) SPENT BOATING= ',T50,F10.1/
     3 20X,'LAKE VOLUME(GALLONS)= ',T50,E15.2//)
   20 FORMAT(E15.7,2F10.1,E15.7)
      READ(1,30)DESDOS,LK1,LK2
   30 FORMAT(I5,A4,A4)
      DO 50 LL=1,L
      IF(JJJ.GT.1)GO TO 31
      READ(1,40)SWIMDF(LL),SKINDF(LL)
   31 CONTINUE
      BOATDF(LL)=.5*SWIMDF(LL)
   50 BOATSK(LL)=.5*SKINDF(LL)
   40 FORMAT(2E15.7)
      READ(1,60)MM,II,WATFAC
   60 FORMAT(3I5)
      IF(JJJ.GT.1)GO TO 61
      DO 14 LL=1,L
      WRITE(3,16)ISO(LL),LATWT(LL)
      WRITE(3,12)ACT(MM,II,LL)
   14 WRITE(3,13)SWIMDF(LL),SKINDF(LL),BOATDF(LL),BOATSK(LL)
   13 FORMAT('0'//10X,'WHOLE BODY SWIMMING DOSE FACTOR(MREM/HR PER ',
     1'PCI/L)= ',T75,E15.3/10X,'SKIN SWIMMING DOSE FACTOR',
     2 '(MREM/HR PER PCI/L)= ',T75,E15.3/10X,'WHOLE BODY BOATING ',
     3 'DOSE FACTOR(MREM/HR PER PCI/L)= ',T75,E15.3/10X,
     4 'SKIN BOATING DOSE FACTOR(MREM/HR PER PCI/L)= ',T75,E15.3//)
   16 FORMAT('0'/2X,'FOR: ',A4,A4/)
C
C     COMPUTE WATER CONCENTRATIONS AND DOSES IN MREM
C
C     FIX THE LOCATION OF THE LAKE
C
   61 CONTINUE
      DO 70 LL=1,L
      CON(LL)=(ACT(MM,II,LL)*.0929*SURF)/(VOLUME*3.78541)
   12 FORMAT('0'/20X,'ACTIVITY DENSITY(PCI/M**2)= ',E15.2/)
      DOSSWB(LL)=CON(LL)*SWIMDF(LL)*SWIM
      DOSBWB(LL)=CON(LL)*BOATDF(LL)*BOAT
      DOSSSK(LL)=CON(LL)*SKINDF(LL)*SWIM
   70 DOSBSK(LL)=CON(LL)*BOATSK(LL)*BOAT
      WRITE(3,80)LK1,LK2
   80 FORMAT('1'///////23X,'THE FOLLOWING IS A LISTING OF RADIONUCLIDE',
     1' CONCENTRATIONS IN LAKE ',2A4,'BY ISOTOPE'///)
      DO 100 LL=1,L
  100 WRITE(3,90)ISO(LL),LATWT(LL),CON(LL)
   90 FORMAT('0',39X,'THE CONCENTRATION OF',A4,2X,A4,' IS ',E15.7,
     1 2X,' PCI/L '/)
      TOTCON=0.
      DO 110 LL=1,L
  110 TOTCON=CON(LL)+TOTCON
      WRITE(3,120)LK1,LK2,TOTCON
  120 FORMAT('0'/////13X,'THE TOTAL NUCLIDE CONCENTRATION',
     1 ' IN LAKE ',2A4,' IS ',E15.3,2X,'PCI/L FOR THE UNTREATED ',
     2 'WATER'///)
      IF(SWIM.EQ.0.)GO TO 220
```

```
      IF(DESDOS.EQ.1)GO TO 170
      DO 140 LL=1,L
      IF(DOSSWB(LL).EQ .0.)GO TO 140
      WRITE(3,130)LK1,LK2,SWIM,ISC(LL),LATWT(LL),DOSSWB(LL)
  140 CONTINUE
  130 FORMAT(' ',14X,'THE WHOLE BODY DOSE DUE TO SWIMMING IN LAKE ',
     1 2A4,' FOR ',F5.1,2X,'HOURS DUE TO ',A4,A4,3X,'IS',E15.7,2X,
     2 'MREM'/)
      TOTDOS=0.
      DO 150 LL=1,L
  150 TOTDOS=TOTDOS+DOSSWB(LL)
      WRITE(3,160)LK1,LK2,TOTDOS
  160 FORMAT(' ',19X,'THE TOTAL WHOLE BODY DOSE DUE TO SWIMMING',
     1'FROM ALL NUCLIDES IN LAKE ',2A4,2X,' IS ',E15.2,2X,'MREM')
      IF(DESDOS.EQ.0)GO TO 220
  170 CONTINUE
      DO 180 LL=1,L
      IF(DOSSSK(LL).EQ.0.) GO TO 180
      WRITE(3,190)LK1,LK2,SWIM,ISC(LL),LATWT(LL),DOSSSK(LL)
  180 CONTINUE
  190 FORMAT(' ',17X,'THE SKIN DOSE DUE TO SWIMMING IN LAKE ',
     1 2A4,' FOR ',F5.1,2X,'HOURS DUE TO ',A4,A4,3X,' IS ',
     2 E15.7,2X,'MREM'/)
      TOTDOS=0.
      DO 200 LL=1,L
  200 TOTDOS=TOTDOS+DOSSSK(LL)
      WRITE(3,210)LK1,LK2,TOTDOS
  210 FORMAT(' ',22X,'THE TOTAL SKIN DOSE DUE TO SWIMMING FROM ALL',
     1 ' NUCLIDES IN LAKE ',2A4,2X,' IS ',E15.3,2X,'MREM')
  220 CONTINUE
      IF(BOAT.EQ.0.)GO TO 320
      IF(DESDOS.EQ.1)GO TO 270
      DO 230 LL=1,L
      IF(DOSBWB(LL).EQ.0.)GO TO 230
      WRITE(3,240)LK1,LK2,BOAT,ISC(LL),LATWT(LL),DOSBWB(LL)
  230 CONTINUE
  240 FORMAT(' ',14X,'THE WHOLE BODY DOSE DUE TO BOATING ON LAKE ',
     12A4,' FOR ',F5.1,2X,'HOURS DUE TO ',A4,A4,3X,' IS ',E15.3,2X,
     2 'MREM')
      TOTDOS=0.
      DO 250 LL=1,L
  250 TOTDOS=TOTDOS+DOSBWB(LL)
      WRITE(3,260)LK1,LK2,TOTDOS
  260 FORMAT(' ',20X,'THE TOTAL WHOLE BODY DOSE DUE TO BOATING ',
     1 'FROM ALL NUCLIDES IN LAKE ',2A4,2X,' IS ',E15.2,'MREM')
      IF(DESDOS.EQ.0)GO TO 320
  270 CONTINUE
      DO 280 LL=1,L
      IF(DOSBSK(LL).EQ.0.)GO TO 280
      WRITE(3,290)LK1,LK2,SWIM,ISC(LL),LATWT(LL),DOSBSK(LL)
  280 CONTINUE
  290 FORMAT(' ',18X,'THE SKIN DOSE DUE TO BOATING IN LAKE ',2A4,
     1 ' FOR ',F5.1,2X,'HOURS DUE TO ',2A4,3X,'IS ',E15.3,' MREM')
      TOTDOS=0.
      DO 300 LL=1,L
  300 TOTDOS=TOTDOS+DOSBSK(LL)
      WRITE(3,310)LK1,LK2,TOTDOS
  310 FORMAT(' ',22X,'THE TOTAL SKIN DOSE DUE TO BOATING FROM ALL ',
     1 ' NUCLIDES IN LAKE ',2A4,2X,' IS ',E15.2,2X,'MREM')
  320 CONTINUE
```

```
      SUM=0.
      WRITE(3,5C0)WATFAC
  500 FORMAT(' ',50X,'TREATMENT FACILITY CLASS= ',I5)
      DO 400 LL=1,L
      IF(WATFAC.EQ.1)GO TO 350
      IF(WATFAC.EQ.2)GO TO 360
      IF(WATFAC.GT.2)GO TO 370
      WRITE(3,340)
      GO TO 481
  350 FINAL(LL)=CON(LL)
      GO TO 380
  360 FINAL(LL)=CON(LL)*SOLUB(LL)
      GO TO 380
  370 FINAL(LL)=FRACT(LL)*CON(LL)*SOLUB(LL)
  380 CONTINUE
      SUM=SUM+FINAL(LL)
  400 CONTINUE
  340 FORMAT(' ',37X,'THERE IS NO WATER TREATMENT')
      WRITE(3,410)WATFAC
  410 FORMAT(' ',28X,'AFTER WATER TREATMENT, THE FOLLOWING ',
     1 'CONCENTRATIONS ARE PRESENT IN THE WATER'/
     2 38X,'THE WATER WAS TREATED IN A CLASS ',I5,2X,'TREATMENT ',
     3 'FACILITY')
      WRITE(3,420)
  420 FORMAT('0',37X,'ISOTOPE',10X,'ATOMIC WEIGHT',10X,'CONCENTRATION',
     1 '(PCI/L)'///)
      DO 430 LL=1,L
  430 WRITE(3,440)ISO(LL),LATWT(LL),FINAL(LL)
  440 FORMAT(' ',40X,A4,14X,A4,18X,E15.3)
  460 WRITE(3,470)SUM
  470 FORMAT('0'///39X,'THE TOTAL RADIONUCLIDE CONCENTRATION IS ',
     1 E15.7,' PCI/L'/39X,'DECAY EN ROUTE TO WATER USAGE IS NOT ',
     2 'CONSIDERED.'////)
  481 CONTINUE
      CALL FISHL(CON,MM,II,ISO,LATWT,L)
  482 CONTINUE
      CALL MILK(L,M,I,ISO,LATWT,XLAMBD,CON,FRACT,SOLUB)
  480 RETURN
      END
      SUBROUTINE FISHL(CON,MM,II,ISO,LATWT,L)
      DIMENSION CON(20),ISO(20),LATWT(20),CR(20),FISHCN(20)
      COMMON/THREE/CF(20)
      DO 10 LL=1,L
      IF(CF(LL).EQ.0.)GO TO 100
   10 CONTINUE
   20 FORMAT(F10.0)
      FISHT=0.
      DO 30 LL=1,L
      FISHCN(LL)=CON(LL)*CF(LL)
   30 FISHT=FISHT+FISHCN(LL)
      WRITE(3,40)
   40 FORMAT('-'///////'*************************************************',
     1'*************************************************************'///)
      DO 42 LL=1,L
      IF(LL.GT.1)GO TO 42
      WRITE(3,41)ISO(LL),LATWT(LL),CF(LL)
   42 CONTINUE
   41 FORMAT(' ','CONCENTRATION FACTORS'/48X,A4,A4,2X,' = ',
     1 F10.0,' PCI/KG PER PCI/L')
      WRITE(3,50)
```

```
 50 FORMAT('-'////////41X,'NUCLIDE CONCENTRATION IN FISH LOCATED',
   1 ' IN THE LAKE'//////)
    DO 60 LL=1,L
    IF(FISHCN(LL).EQ.0.)GO TO 60
    WRITE(3,70)ISO(LL),LATWT(LL),FISHCN(LL)
 60 CONTINUE
 70 FORMAT(' ',46X,A4,A4,' = ',10X,E15.2,'PCI/KG')
    WRITE(3,80)FISHT
 80 FORMAT('-'////42X,'THE TOTAL CONCENTRATION = ',E15.2,2X,'PCI/KG'
   1 //)
    WRITE(3,90)
 90 FORMAT('0'//'*****************************************************',
   1'************************************************************'///)
100 RETURN
    END
    SUBROUTINE FISHR(CONCEN,RADIUS,SECTOR,ISO,LATWT,L,IIRECH,NUMB)
    DIMENSION RADIUS(20),SECTOR(20),CONCEN(20,20),ISO(20),
   1 LATWT(20),FISHCN(20,20),NUMB(20),FISHT(20)
    COMMON/THREE/CF(20)
    DO 10 LL=1,L
    READ(1,20)CF(LL)
    IF(CF(LL).EQ.0.)GO TO 130
 10 CONTINUE
 20 FORMAT(F10.0)
    DO 40 IREACH=2,IIRECH
    FISHT(IREACH)=0.
    DO 40 LL=1,L
    FISHCN(IREACH,LL)=CONCEN(IREACH,LL)*CF(LL)
 40 FISHT(IREACH)=FISHT(IREACH)+FISHCN(IREACH,LL)
    WRITE(3,60)
    WRITE(3,50)
 50 FORMAT(' ',41X,'NUCLIDE CONCENTRATION IN FISH LOCATED ',
   1 'IN THE RIVER')
 60 FORMAT('-'//////'*****************************************************',
   1'************************************************************'///)
    DO 100 IREACH=2,IIRECH
    WRITE(3,70)NUMB(IREACH)
    DO 90 LL=1,L
    IF(FISHCN(IREACH,LL).EQ.0.)GO TO 90
    WRITE(3,80)ISO(LL),LATWT(LL),FISHCN(IREACH,LL)
 90 CONTINUE
100 WRITE(3,110)FISHT(IREACH)
 70 FORMAT(' ',61X,'REACH',2X,I5)
 80 FORMAT(' ',46X,A4,A4,' =',10X,E15.2,' PCI/KG')
110 FORMAT(' ',42X,'THE TOTAL CONCENTRATION = ',E15.2,2X,
   1 'PCI/KG')
    WRITE(3,120)
120 FORMAT('0'//'*****************************************************',
   1'************************************************************'//)
130 RETURN
    END
```

```
      SUBROUTINE MILK(L,M,I,ISO,LATWT,XLAMBD,CON,FRACT,SOLUB)
      COMMON/ONE/ACT(12,16,20),XXTIM,CONCEN(20,20)
      INTEGER  RR(20),SS(20)
      INTEGER DRINK(192),RADIUS(192),SECTOR(192),DAY,TOTDAY,WATFAC (192)
      REAL LAMEFF(20),ID
      DIMENSION COWL(20)
      DIMENSION ISO(20),LATWT(20),XLAMBD(20),FRACT(20),SOLUB(20),CON(20)
     1 ,CD(12,16,20),SD(20),TOTAL(12,16),BF(20)
      COMMON/TWO/RR,SS,IIRECH
```

```
      READ(1,30)NUMBER
      WRITE(3,410)
      WRITE(3,90)NUMBER
   30 FORMAT(I5)
      IF(NUMBER.EQ.-1)GO TO 400
      READ(1,10)QF,R,YF
      WRITE(3,100)QF,R,YF
   10 FORMAT(3F10.2)
      READ(1,22)XLD,TAREA,VOL
      WRITE(3,120)XLD,TAREA,VOL
      IF(NUMBER.EQ.0)GO TO 170
      DO 40 J=1,NUMBER
   40 READ(1,20)DRINK(J),RADIUS(J),SECTOR(J),WATFAC(J)
      WRITE(3,141)
      DO 130 J=1,NUMBER
  130 WRITE(3,140)DRINK(J),RADIUS(J),SECTOR(J),WATFAC(J)
   20 FORMAT(4I5)
   31 FORMAT(I5,F10.2)
   21 FORMAT(2F10.2)
   22 FORMAT(3F10.2)
  170 READ(1,50)TOTDAY,INC
  180 WRITE(3,150)TOTDAY,INC
      READ(1,31)LEAVE,BIO
      WRITE(3,230)LEAVE,BIO
   50 FORMAT(2I5)
      DO 501 LL=1,L
  501 READ(1,502)BF(LL)
      DO 889 LL=1,L
  889 WRITE(3,110)BF(LL),ISO(LL),LATWT(LL)
  502 FORMAT(E10.2)
      DO 270 LL=1,L
  270 READ(1,280)SD(LL)
      DO 183 LL=1,L
  183 WRITE(3,290)SD(LL),ISO(LL),LATWT(LL)
  280 FORMAT(E15.1)
      READ(1,888)CBIO
      WRITE(3,901)CBIO
  901 FORMAT(' ',10X,'BIOLOGICAL HALF LIFE IN THE COW= ',F10.2/)
  888 FORMAT(F10.2)
      WRITE(3,160)XXTIM
  160 FORMAT(/10X,'INITIAL TIME(DAYS) AFTER ACCIDENT=',2X,F5.1)
   90 FORMAT('-'///////5X,I5,2X,'= THE NUMBER OF MESH POINTS(MM,II) ',
     1 'THAT USE EXPOSED RIVER OR LAKE WATER FOR COW DRINKING WATER'/)
  100 FORMAT('0',5X,F10.2,2X,'=FRESH FORAGE INGESTION BY ',
     1' THE DAIRY COW(KG/DAY)'/5X,F10.2,2X,'=DEPOSITION ',
     2 'RETENTION FACTOR (FRACTION OF DEPOSITION RETAINED BY THE ',
     3 'FORAGE CROP)'/5X,F10.2,2X,'=FORAGE CROP YIELD(KG/M**2)'/)
  110 FORMAT(' ',5X,F10.2,2X,'=FORAGE CROP CONCENTRATION FACTOR ',
     1 'FOR ',A4,A4,' (PCI/KG PER PCI/KG SOIL)'/)
  120 FORMAT('0',5X,F10.2,2X,'=INGESTION OF DRINKING WATER BY COW ',
     1 '(L/DAY)'/5X,F10.2,2X,'=WATERING TROUGH AREA FROM AN UNDERGROU',
     2 'ND WELL(FT**2)'/5X,F10.2,2X,'VOLUME OF WATERING TROUGH',
     3'(GALLONS)'//)
  140 FORMAT('0',5X,I5,'=DRINKING WATER TYPE (1=RIVER,2=LAKE)'/
     1 5X,I5,'=RADIUS OF MESH POINT USING THE ABOVE DRINKING WATER'/
     2 5X,I5,'=SECTOR OF MESH POINT USING THE AVOVE DRINKING WATER'/
     3 5X,I5,'=SERVICING WATER TREATMENT FACILITY TYPE ',
     4 '(0=NONE,1=CLASS 1,2=CLASS 2,3=CLASS 3,4=CLASS 4'/)
  141 FORMAT('0'////44X,'LOCATIONS USING OTHER THAN UNDERGROUND WELLS'
     1 //)
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150 FORMAT('0'//5X,I5,2X,'=MAXIMUM NUMBER OF DAYS WHEN COMPUTING ',
   1 'MILK CONCENTRATIONS (DAYS AFTER ACCIDENT)'/5X,I5,2X,
   2 '=INCREMENTS(DAYS) BETWEEN COMPUTING SUCCESSIVE CONCENTRATIONS'/)
230 FORMAT('0',5X,I5,2X,'=EVACUATION MODE (0=NO EVACUATION, ',
   1 '1=EVACUATION AFTER ONE DAY''S EXPOSURE)'/5X,F10.2,2X,
   2 '=BIOLOGICAL HALF LIFE OF THE FORAGE CROP IN THE COW(DAYS)'/)
290 FORMAT('0',5X,E15.1,2X,'=COEFFICIENT OF TRANSFER FROM DIET TO ',
   1'MILK(PCI/L PER PCI/DAY) FOR ',A4,A4)
    NXXTIM=XXTIM
    DO 60 DAY=NXXTIM,TOTDAY,INC
    DO 75 MM=1,M
    DO 75 II=1,I
    TOTAL(MM,II)=0.
    DO 70 LL=1,L
    LAMEFF(LL)=XLAMBD(LL)+.693/BIO
    RINC=INC
    XDAY=DAY
    COWL(LL)=XLAMBD(LL)+.693/CBIO
    IF(COWL(LL).LE.1.E-20)COWL(LL)=0.
    DMAX=LAMEFF(LL)*XDAY
    IF(DAY.EQ.NXXTIM)GO TO 79
    IF(LEAVE.EQ.1)GO TO 320
    IF(DMAX.GE.40.)DUMMY=0.
    IF(DMAX .GE.40.)GO TO 81
    DUMMY=CD(MM,II,LL)*(1.-EXP(-COWL(LL)*RINC))
 81 CONTINUE
    IF(DUMMY.LE.1.E-20)DUMMY=0.
    IF(DAY.GT.NXXTIM.AND.LEAVE.EQ.0)GO TO 312
 79 DO 72 J=1,NUMBER
 71 IF(DRINK(J).EQ.1.AND.RADIUS(J).EQ.MM.AND.SECTOR(J).EQ.II)GO TO 190
    IF(DRINK(J).EQ.2.AND.RADIUS(J).EQ.MM.AND.SECTOR(J).EQ.II)GO TO 221
 72 CONTINUE
C
C     DRINKING WATER IS UNDERGROUND,FROM RIVER,OR FROM LAKE
C
191 IF(DMAX.GT.40.)W=0.
    IF(DMAX.GT.40.)GO TO 260
    W=ACT(MM,II,LL)*TAREA*.0929*XLD/(VOL*3.785412) *EXP(-DMAX)
     IF(W.LE.1.E-30)W=0.
    GO TO 260
190 IF(WATFAC(J).EQ.2)GO TO 210
    IF(WATFAC(J).GT.2)GO TO 220
    DO 700 IREACH=1,IIRECH
    IF(RADIUS(J).EQ.RR(IREACH).AND.SECTOR(J).EQ.SS(IREACH))GO TO 701
700 CONTINUE
    CALL REACH(RADIUS,SECTOR)
701 IF(DMAX.GT.40.)W=0.
    IF(DMAX.GT.40.)GO TO 260
    W=CONCEN(IREACH,LL)*XLD   *EXP(-DMAX)
       IF(W.LE.1.E-30)W=0.
    GO TO 260
210 DO 702 IREACH=1,IIRECH
    IF(RADIUS(J).EQ.RR(IREACH).AND.SECTOR(J).EQ.SS(IREACH))GO TO 703
702 CONTINUE
    CALL REACH(RADIUS,SECTOR)
703 IF(DMAX.GT.40.)W=0.
    IF(DMAX.GT.40.)GO TO 260
    W=CONCEN(IREACH,LL)*XLD*SOLUB(LL) *EXP(-DMAX)
    IF(W.LE.1.E-30)W=0.
    GO TO 260
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220 DO 704 IREACH=1,IIRECH
    IF(RADIUS(J).EQ.RR(IREACH).AND.SECTOR(J).EQ.SS(IREACH))GO TO 705
704 CONTINUE
    CALL REACH(RADIUS,SECTOR)
705 IF(DMAX.GT.40.)W=0.
    IF(DMAX.GT.40.)GO TO 260
    W=CONCEN(IREACH,LL)*XLD*FRACT(LL)*SOLUB(LL)  *EXP(-DMAX)
    IF(W.LE.1.E-30)W=0.
    GO TO 260
221 IF(WATFAC(J).EQ.2)GO TO 240
    IF(WATFAC(J).GT.2)GO TO 250
    IF(DMAX.GT.40.)W=0.
    IF(DMAX.GT.40.)GO TO 260
    W=CON(LL)*XLD *EXP(-DMAX)
    IF(W.LE.1.E-30)W=0.
    GO TO 260
240 IF(DMAX.GT.40.)W=0.
    IF(DMAX.GT.40.)GO TO 260
    W=CON(LL)*XLD*SOLUB(LL)*EXP(-DMAX)
    IF(W.LE.1.E-30)W=0.
    GO TO 260
250 IF(DMAX.GT.40.)W=0.
    IF(DMAX.GT.40.)GO TO 260
    W=CON(LL)*XLD*FRACT(LL)*SOLUB(LL)*EXP(-DMAX)
     IF(W.LE.1.E-30)W=0.
260 CONTINUE
C
C   COMPUTE MILK CONCENTRATIONS
C
    ID=QF*(R*ACT(MM,II,LL)/YF+BF(LL)*ACT(MM,II,LL)/224.)+W
    IF(ID.LE.1.E-50)ID=0.
    CD(MM,II,LL)=SD(LL)*ID
    IF(CD(MM,II,LL).LE.1.E-20)CD(MM,II,LL)=0.
    IF(DAY.EQ.NXXTIM)GO TO 300
    CD(MM,II,LL)=CD(MM,II,LL)*EXP(-DMAX)
    IF(CD(MM,II,LL).LE.1.E-20)CD(MM,II,LL)=0.
300 IF(LEAVE.EQ.0.AND.DAY.GT.NXXTIM)GO TO 312
310 CONTINUE
    GO TO 311
312 CD(MM,II,LL)=DUMMY*EXP(-LAMEFF(LL)*RINC)
    IF(CD(MM,II,LL).LE.1.E-20)CD(MM,II,LL)=0.
311 CONTINUE
    IF(DAY.EQ.NXXTIM)GO TO 322
    IF(LEAVE.EQ.0)GO TO 321
320 CONTINUE
    CD(MM,II,LL)=CD(MM,II,LL)*EXP(-COWL(LL)*RINC)
    IF(CD(MM,II,LL).LE.1.E-20)CD(MM,II,LL)=0.
    GO TO 321
322 XMAX=LAMEFF(LL)*XXTIM
    IF(XMAX.GE.40.)CD(MM,II,LL)=0.
    IF(XMAX.GE.40.)GO TO 83
    CD(MM,II,LL)=CD(MM,II,LL)*EXP(-XMAX)
 83 CONTINUE
    IF(CD(MM,II,LL).LE.1.E-20)CD(MM,II,LL)=0.
321 TOTAL(MM,II)=TOTAL(MM,II)+CD(MM,II,LL)
    IF(TOTAL(MM,II).LE.1.E-20)TOTAL(MM,II)=0.
 70 CONTINUE
 75 CONTINUE
    DO 350 LL=1,L
    WRITE(3,340)ISO(LL),LATWT(LL),DAY
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      WRITE(3,330)
      DO 350 MM=1,M
  350 WRITE(3,360)(MM,(CD(MM,II,LL),II=1,I))
      WRITE(3,420)DAY
      WRITE(3,330)
      DO 430 MM=1,M
  430 WRITE(3,360)(MM,(TOTAL(MM,II),II=1,I))
      SUM=0.
      DO 370 LL=1,L
      DO 370 MM=1,M
      DO 370 II=1,I
      IF(CD(MM,II,LL).LE.1.E-10)CD(MM,II,LL)=0.
  370 SUM=SUM+CD(MM,II,LL)
      IF(SUM.EQ.0.)GO TO 380
   60 CONTINUE
      GO TO 400
  330 FORMAT('0'///1X,'MM',3X,'N',5X,'NNE',4X,'NE',5X,'ENE',5X,'E',5X,
     1 'ESE',4X,'SE',5X,'SSE',5X,'S',5X,'SSW',4X,
     2 'SW',5X,'WSW',4X,'W',6X,'WNW',4X,'NW',5X,'NNW'/)
  340 FORMAT('0'////44X,A4,A4,3X,'CONCENTRATIONS(PCI/L) AFTER ',
     1 I4,2X,'DAYS'//)
  360 FORMAT(' ',I2,2X,16E7.2)
  380 WRITE(3,390)
  390 FORMAT('0'////10X,'PROGRAM TERMINATED. ALL MILK CONCENTRATIONS ',
     1 ' ARE LESS THAN 1E-10 PCI/L')
  410 FORMAT('1'////////'*********************************************',
     1'***************************************************************',
     2'*********************'/
     3                   '*********************************************',
     1'***************************************************************',
     4'*********************'/////
     5 49X,'RADIONUCLIDE CONCENTRATIONS IN MILK'///)
  420 FORMAT('0'////43X,'TOTAL CONCENTRATION(PCI/L) AFTER ',I4,2X,
     1'DAYS'//'*******************************************************',
     2'***************************************************************',
     3 '****'///)
  400 RETURN
      END
      SUBROUTINE REACH(RADIUS,SECTOR)
C
C   COMPUTES THE CLOSEST REACH PROVIDING WATER
C
      DIMENSION  XRADIU(1),XSECTO(1),XRR(12),XSS(16)
      COMMON/TWO/RR,SS,IIRECH
      INTEGER RADIUS(1),SECTOR(1),RR(12),SS(16)
      XMIN=10000.
      XRADIU(J)=RADIUS(J)
      XSECTO(J)=SECTOR(J)
      DO 2 IREACH=2,IIRECH
      IIRECH=IIRECH+1
      XRR(IREACH)=RR(IREACH)
      XSS(IREACH)=SS(IREACH)
      A=ABS(XRADIU(J)-XRR(IREACH))
      B=ABS(XSECTO(J)-XSS(IREACH))
      C=SQRT(A**2+B**2)
      IF(C.GT.XMIN)GO TO 2
      XMIN=C
      IRMIN=IREACH
    2 CONTINUE
      IREACH=IRMIN
```

```
      WRITE(3,3)IREACH
    3 FORMAT('0'//5X,'THE CLOSEST RIVER REACH TC PROVIDE WATER ',
     1 'IS NUMBER ',2X,I5//)
      RETURN
      END
```